Xmit

NASA CR-112328

EARTH ORBITAL EXPERIMENT PROGRAM
AND
REQUIREMENTS STUDY

VOLUME 4

SPACE ASTRONOMY

(APPENDICES A, B, C, D)

AND

SPACE PHYSICS

(APPENDICES A, B, C)

Prepared under Contract No. NAS1-9464 by
McDONNELL DOUGLAS CORPORATION
5301 Bolsa Avenue
Huntington Beach, California 92647

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

(NASA-CR-112328) EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY. VOLUME 4: SPACE ASTRONOMY (APPENDICES A, B, C, D) AND SPACE PHYSICS (McDonnell-Douglas Corp.) 380 p HC $21.00 CSCL 22A G3/30

N73-22781

Unclas
69829

FOREWORD

The information presented in this report summarizes three major steps toward production of a reference manual for planners of manned earth-orbital research activity. The reference manual will serve as one of the principal tools of a systems approach to experiment and mission planning based on an integrated consideration of candidate research programs and their attendant vehicle, mission, and technology development requirements.

The first major step toward preparation of the manual was the development of long-range goals and objectives suitable for NASA's activities during the 1970-1980 time period. This work was completed by NASA Headquarters with active center support and was published in September 1969 as a portion of a report for the President's Space Task Group entitled, "America's Next Decade in Space."

The second major step was a contractual study effort undertaken in September 1969 by McDonnell Douglas Astronautics Company-West with the TRW Systems Group, the IBM Federal Systems Division, and the RPC Corporation. The purpose of the study was to structure the NASA-developed goals and objectives into an orderly, system-oriented set of implementation requirements. The contractor examined, in depth, the orbital experiment program required to achieve the scientific, technological, and application objectives, and determined in a general way the capabilities required in future manned orbital programs to accommodate the defined experiments. Thus, the basic task of the contractor was to aid NASA in studying the useful and proper roles of manned and automated spacecraft by examining the implementation alternatives for NASA experiments.

The third major step presented in this document is the result of an integrated consideration of NASA's long-range goals and objectives, the system and mission requirements, and the alternative implementation plans. It will serve as a source of detailed information and methodology for use by NASA planners in development and justification of future programs.

Management

Technical direction (fig. 1) of the contracted study effort is the responsibility of the Advanced Aerospace Studies Branch (AASB) of the Space Systems Division (SSD) at the Langley Research Center (LRC). Technical guidance is provided by the Earth Orbital Experiment Program Steering Group which reports through the Planning Steering Group (PSG) to the Associate Administrator. Technical coordination is also maintained with appropriate personnel at ARC, GSFC, MSC, and MSFC.

The membership of the Steering Group (fig. 2) comprises representatives of the working groups of the PSG under the chairmanship of Dr. R. G. Wilson, Director, Advanced Programs, OSSA. The NASA Study Management Team is headed by Mr. W. R. Hook of the AASB. Technical support is supplied by elements of the Langley Research Center as required.

The contractor's Study Team is headed by Dr. H. L. Wolbers, MDAC, and the Senior Management Review Council is chaired by Mr. C. J. Dorrenbacher, Vice President, Advanced Systems and Technology, MDAC.

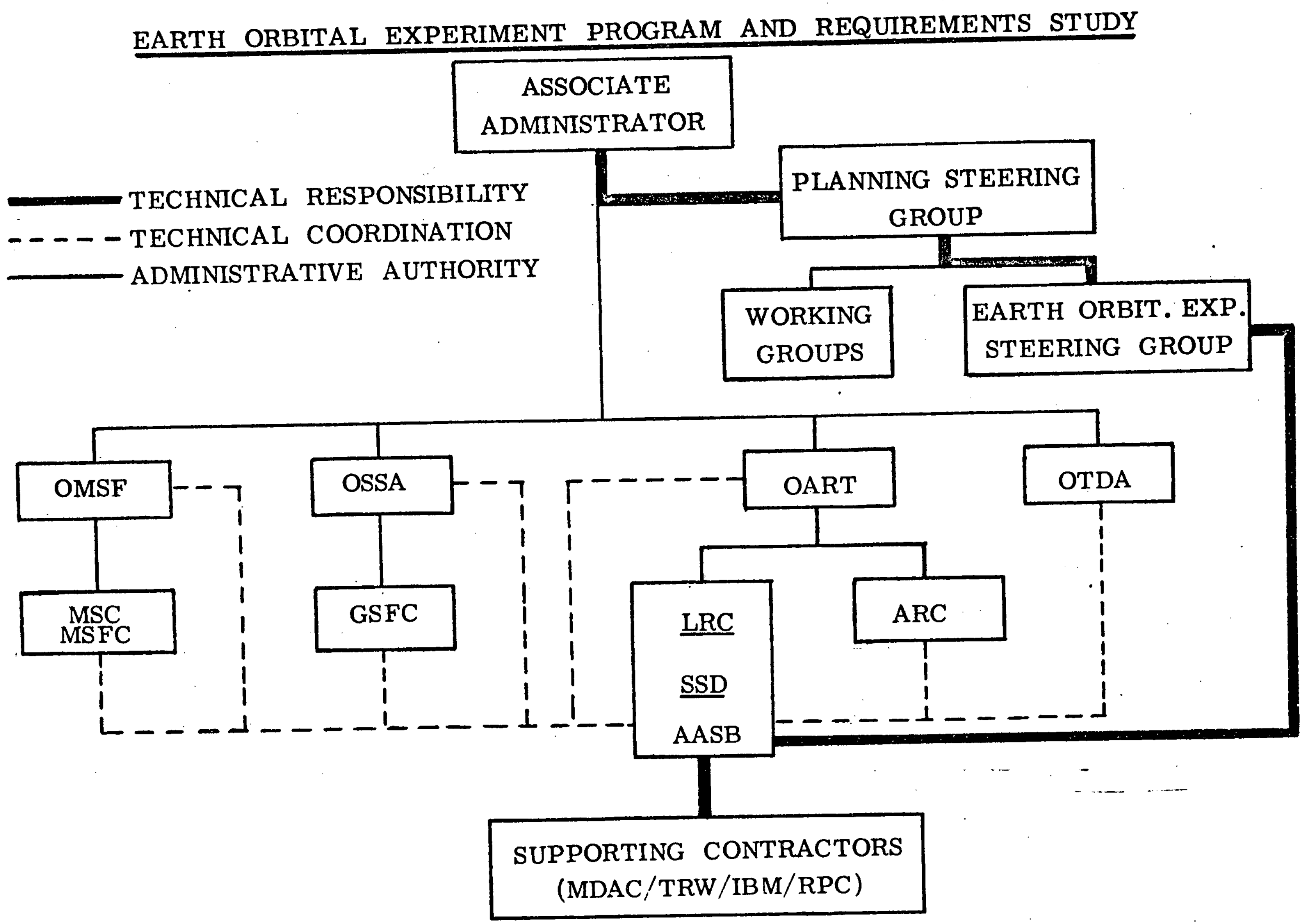


Figure 1. - Management Plan.

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

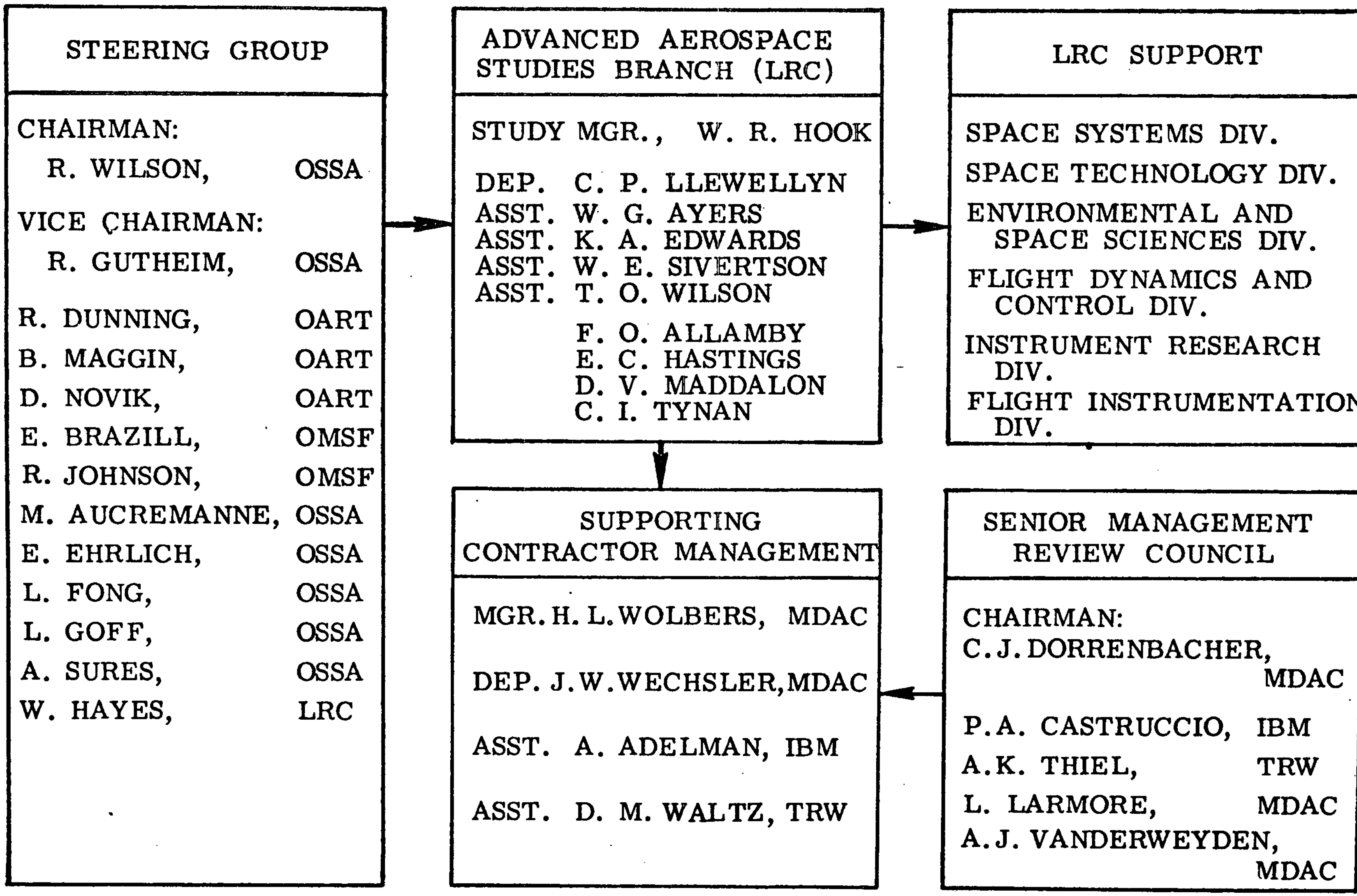


Figure 2. - Study Team.

APPENDIX A

ORGANIZED OVERVIEW CHARTS

SPACE ASTRONOMY

A-1

Appendix A
INTRODUCTION

The organized overview method of analysis is described in Section 2, in general terms as well as specific detail for each of the six study disciplines. The organized overview charts derived in each of these disciplines are presented in this Appendix, as follows:

Manned Spaceflight Capability	Charts 1-1 through 1-90
Space Biology	Charts 2-1 through 2-14
Space Astronomy	Charts 3-1 through 3-42
Space Physics	Charts 4-1 through 4-17
Communications and Navigation	Charts 5-1 through 5-9
Earth Observations	Charts 6-1 through 6-29

Critical issues referred to at the lower levels of these charts are found in Tables 1 through 6 in Appendix B.

Chart 3-1. Organized Overview for Astronomy

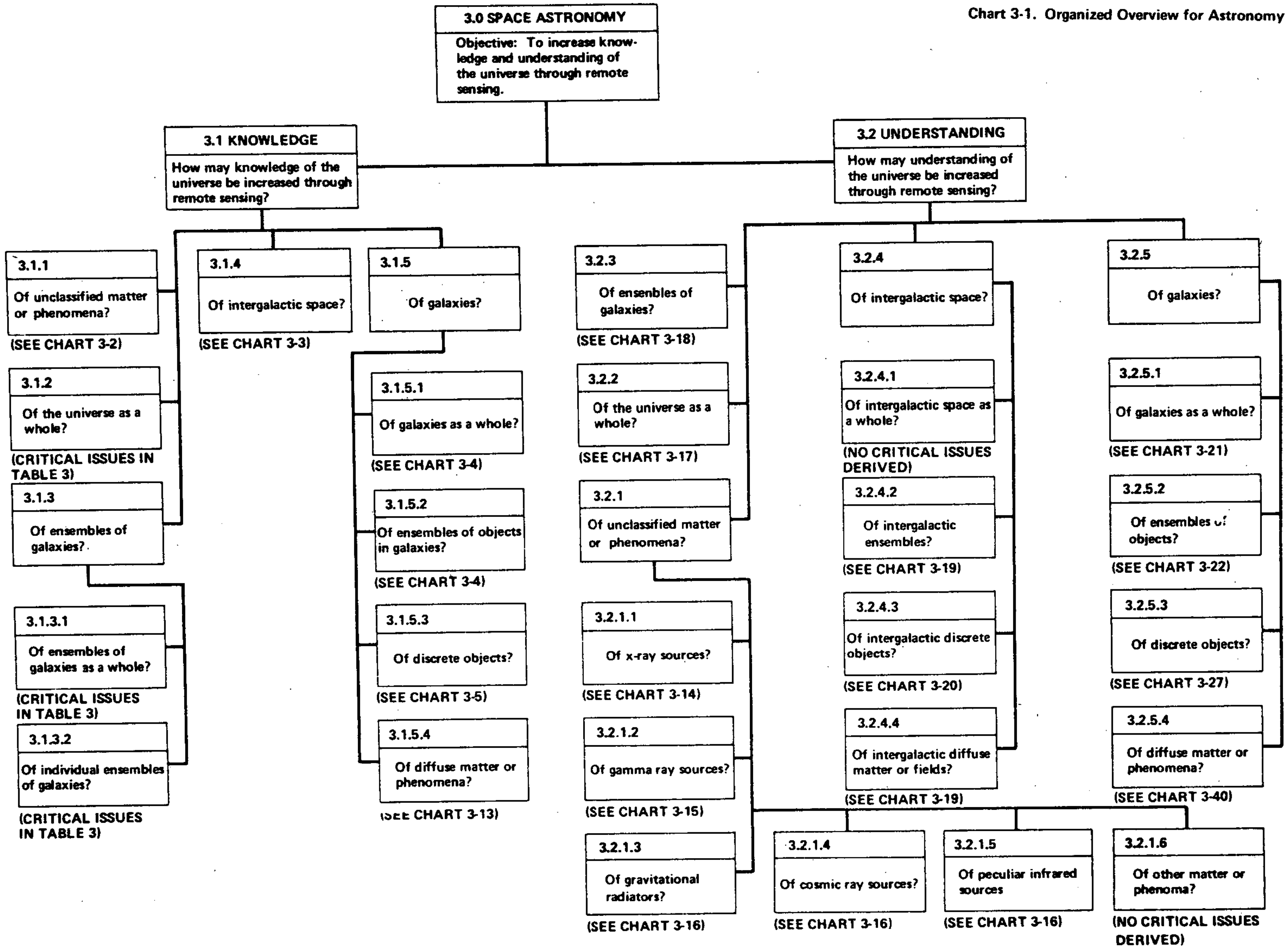
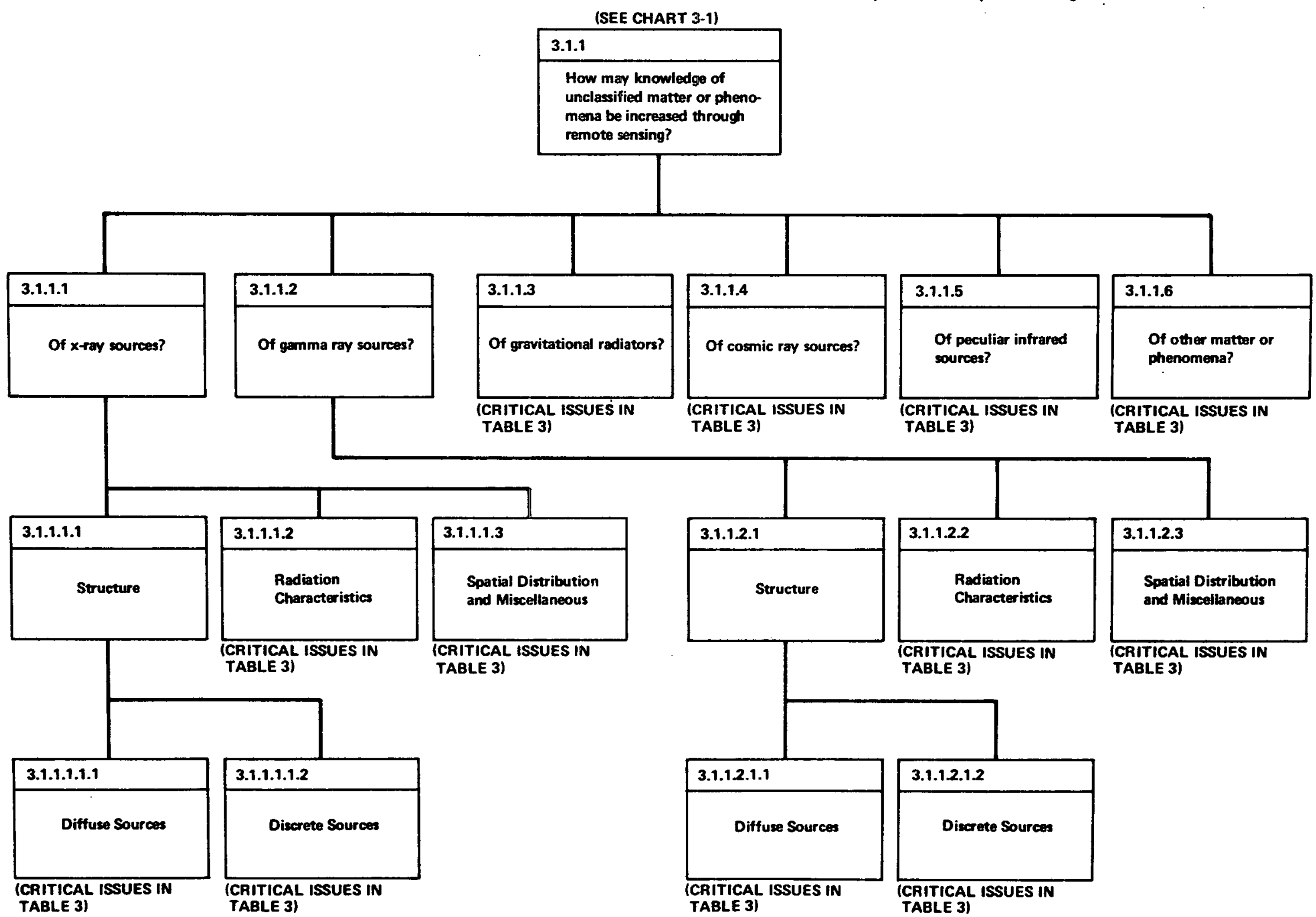


Chart 3-2. Space Astronomy – Knowledge of Unclassified Matter or Phenomena



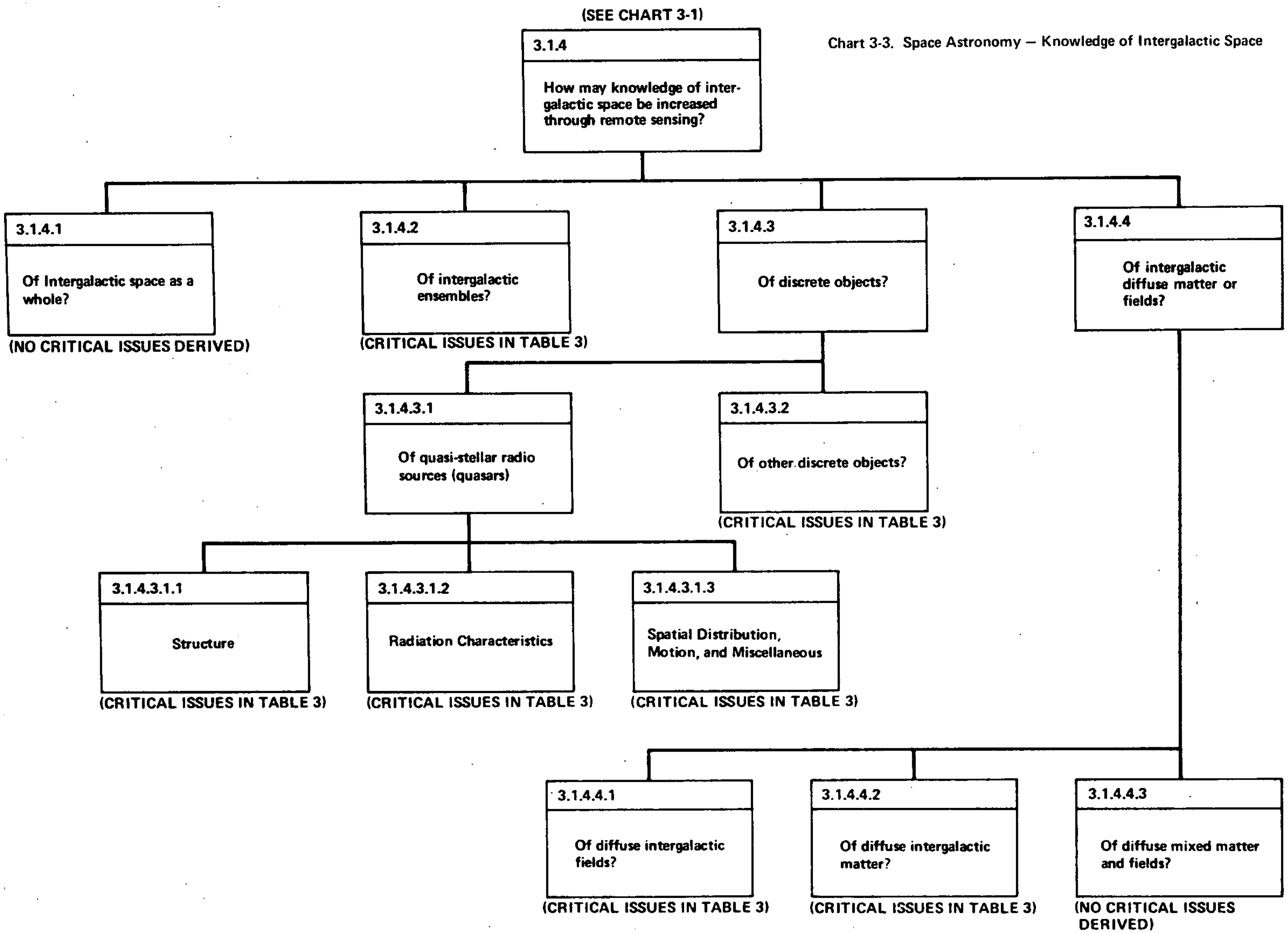
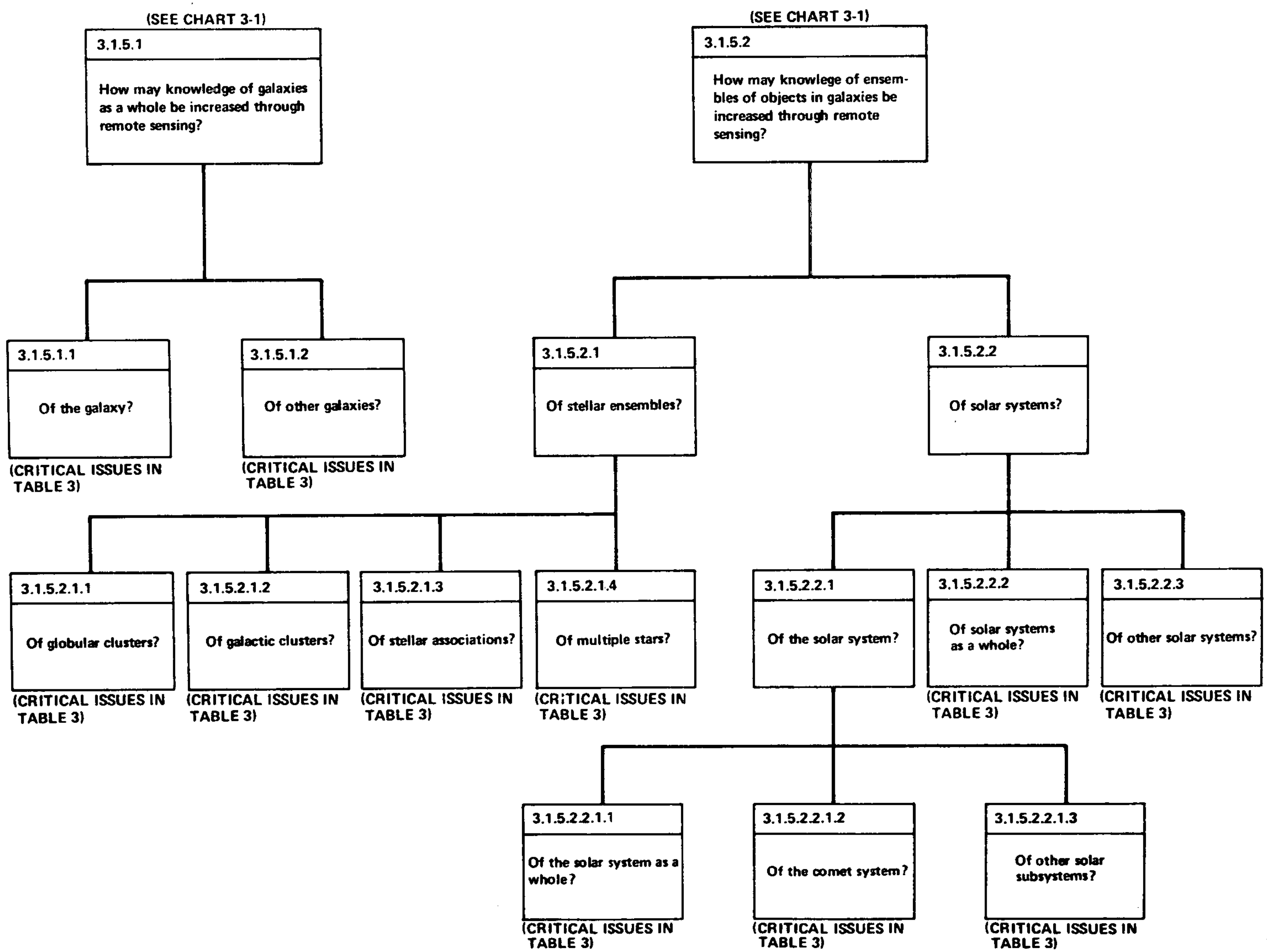


Chart 3-3. Space Astronomy – Knowledge of Intergalactic Space

Chart 3-4. Space Astronomy – Knowledge of Galaxies as a Whole and Ensembles in Galaxies



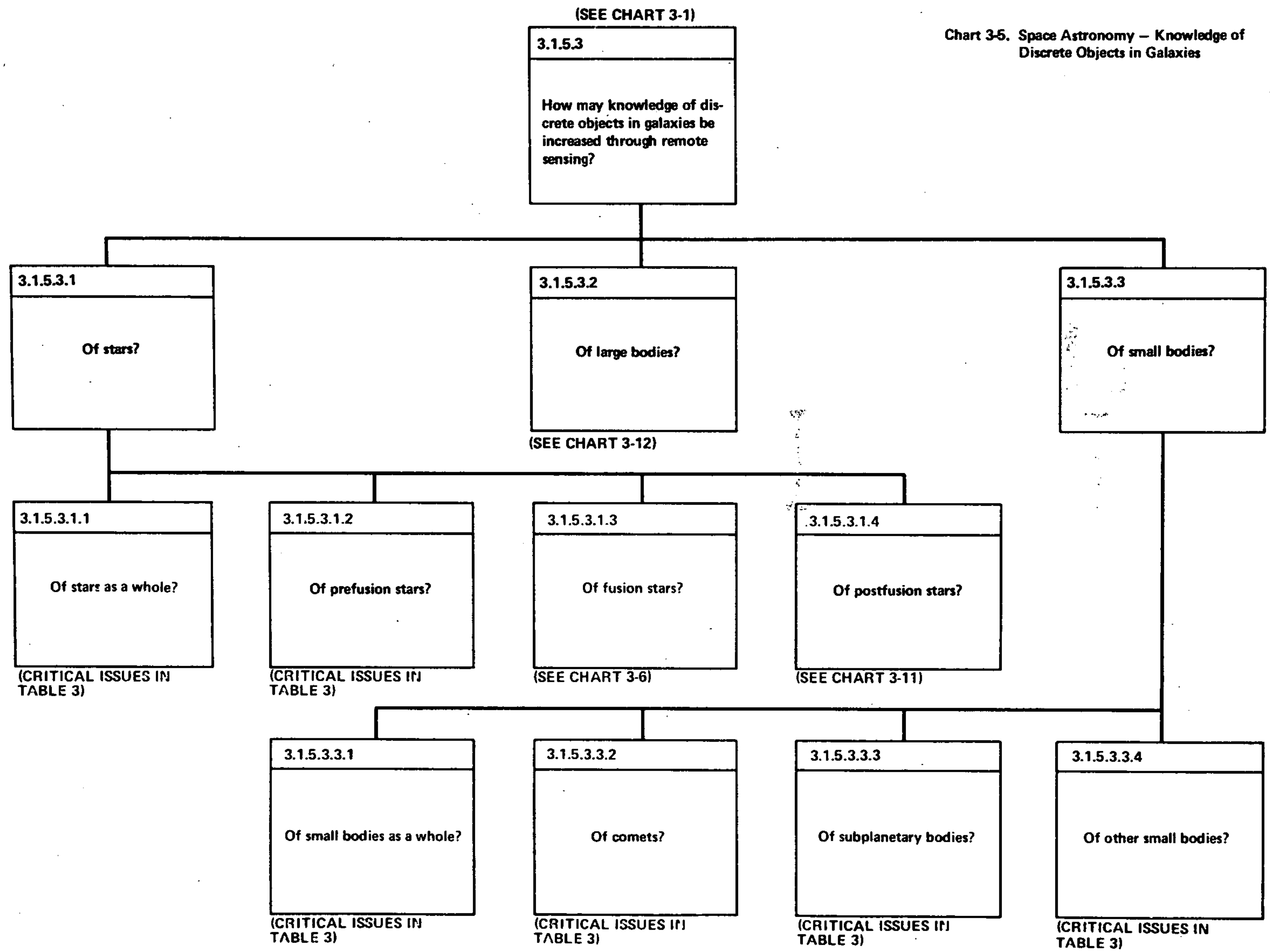


Chart 3-5. Space Astronomy – Knowledge of Discrete Objects in Galaxies

Chart 3-6. Space Astronomy – Knowledge of Fusion Stars in Galaxies

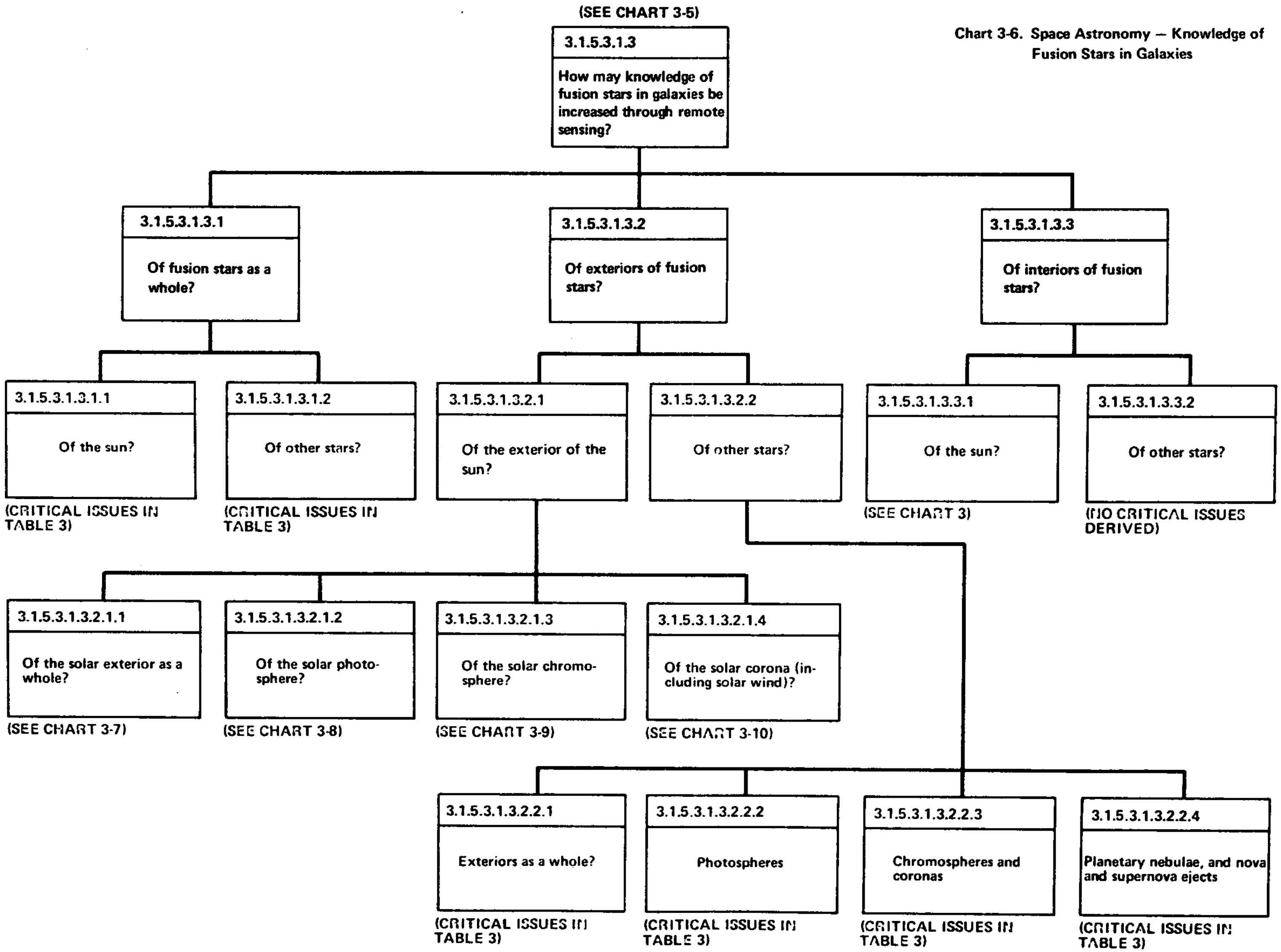


Chart 3-7. Space Astronomy – Knowledge of the Solar Exterior as a Whole

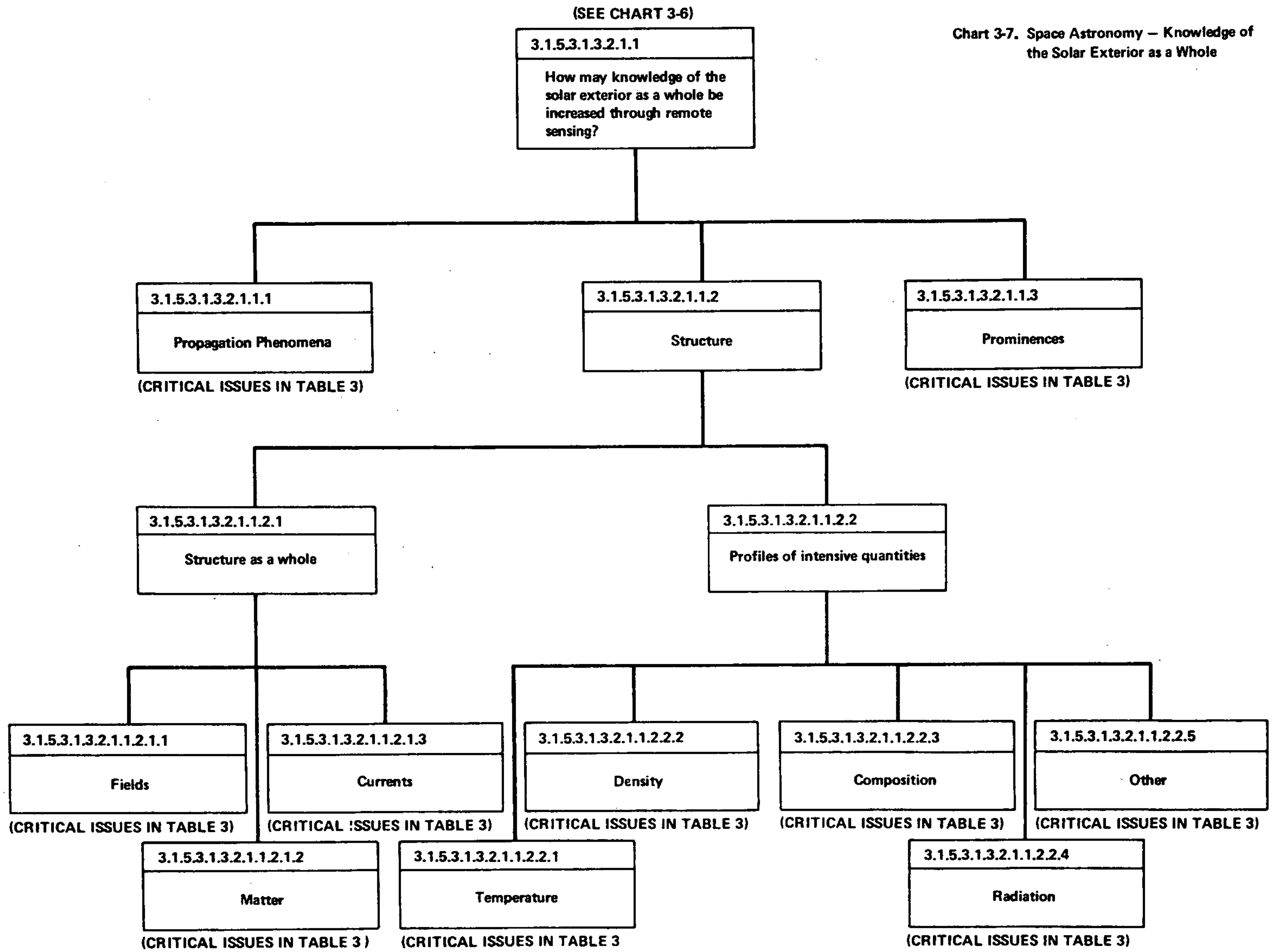
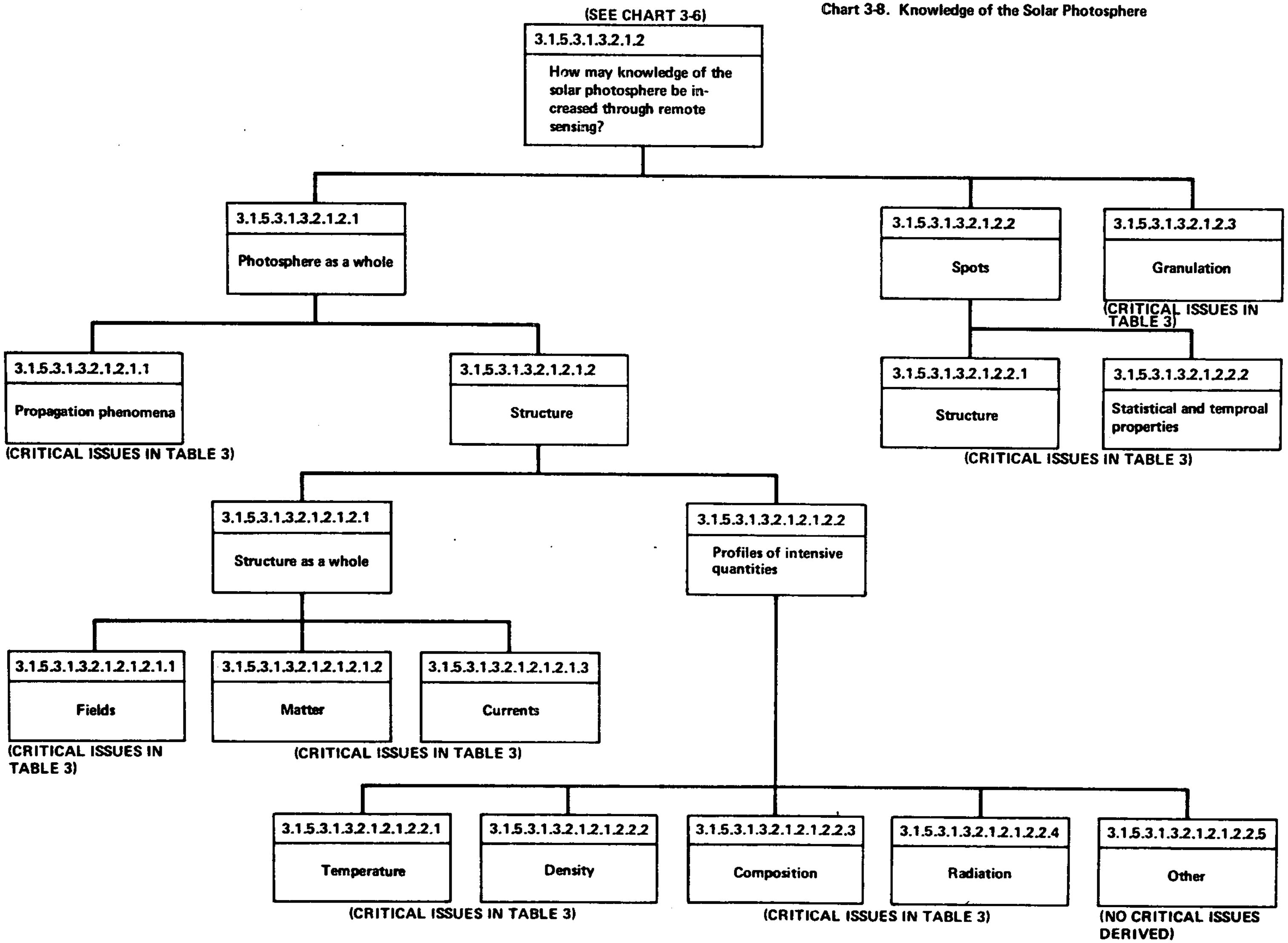


Chart 3-8. Knowledge of the Solar Photosphere



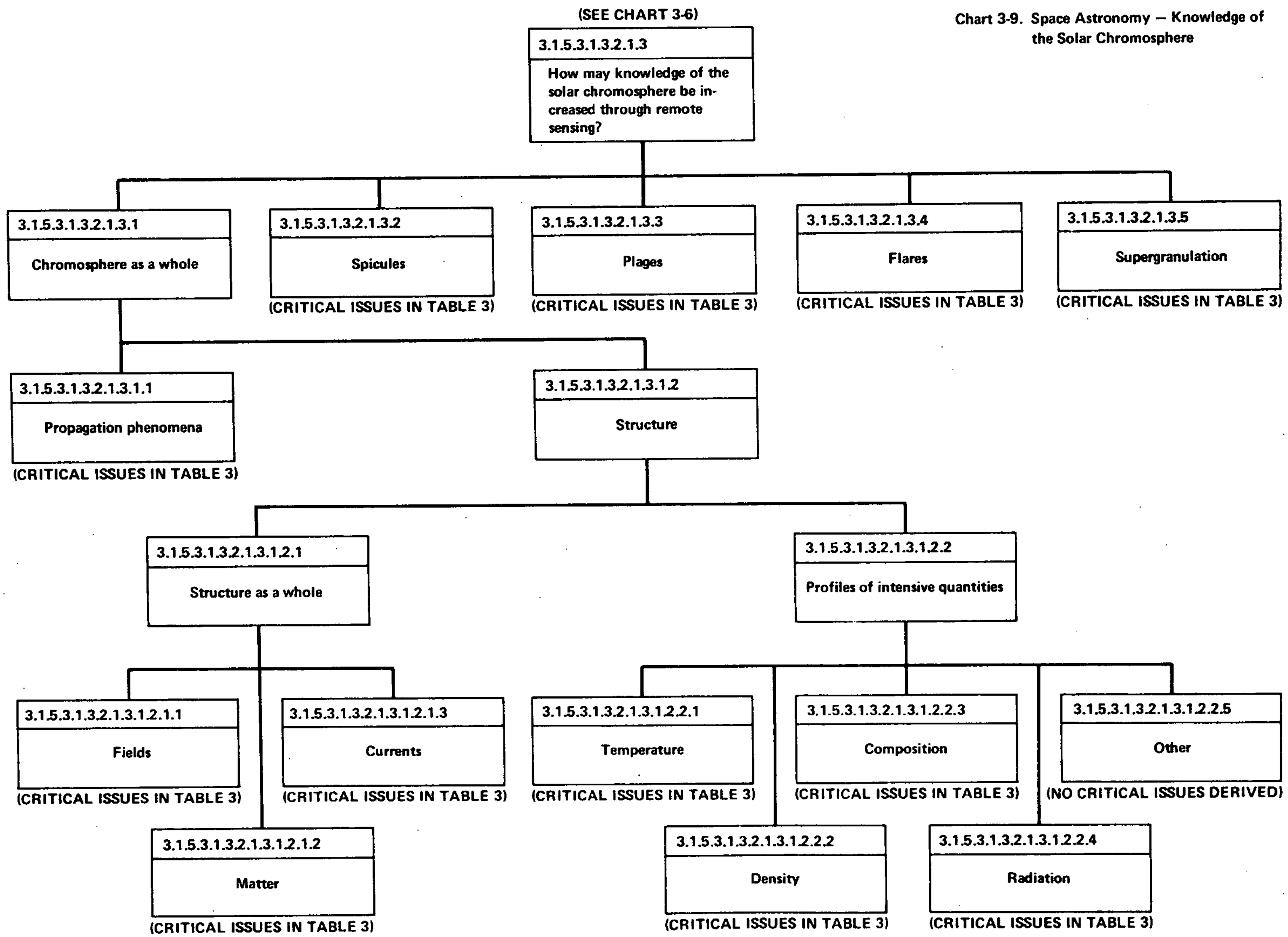


Chart 3-9. Space Astronomy – Knowledge of the Solar Chromosphere

Chart 3-10. Space Astronomy – Knowledge of the Solar Corona (Including Solar Wind)

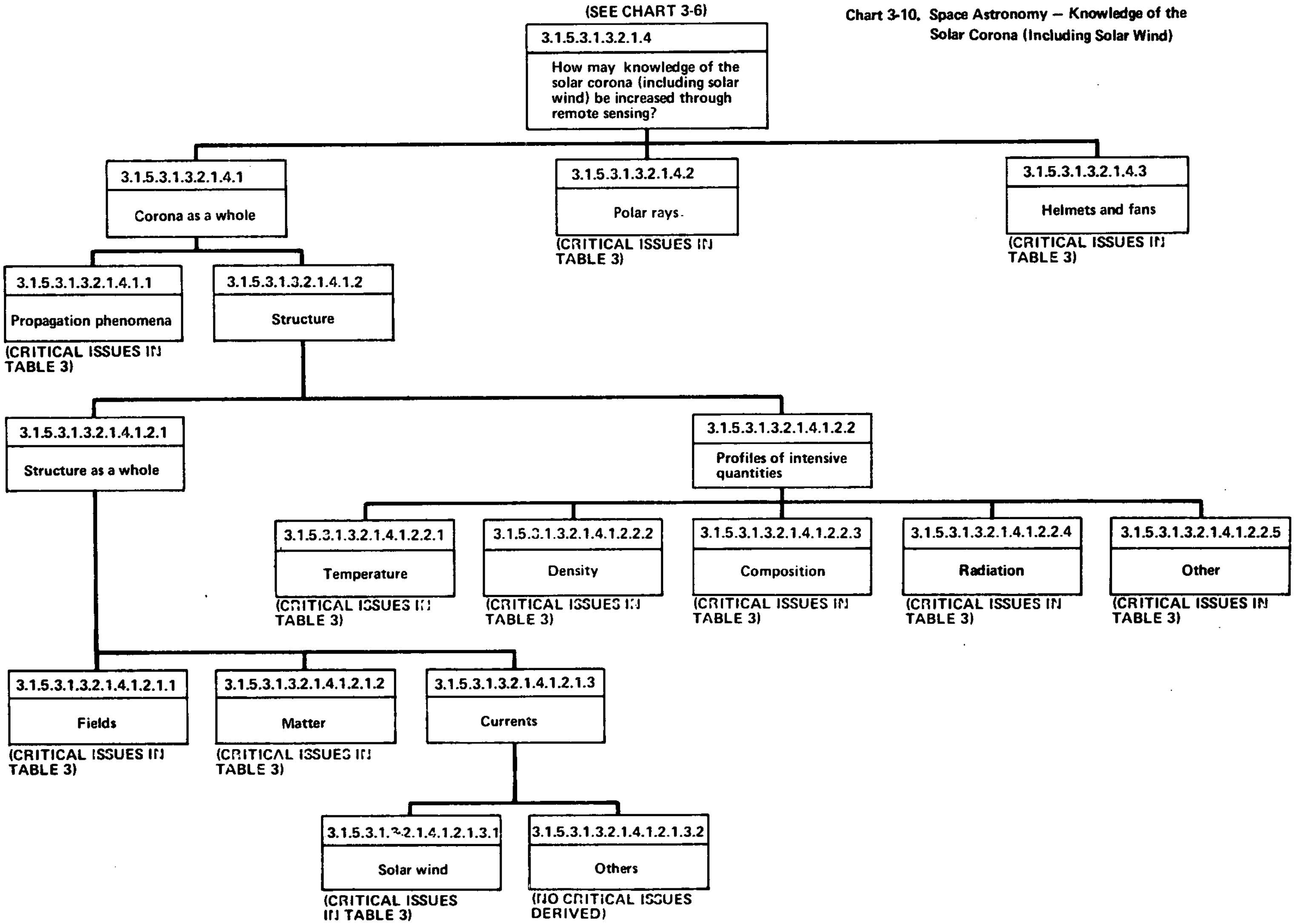


Chart 3-11. Space Astronomy – Knowledge of Postfusion Stars in Galaxies

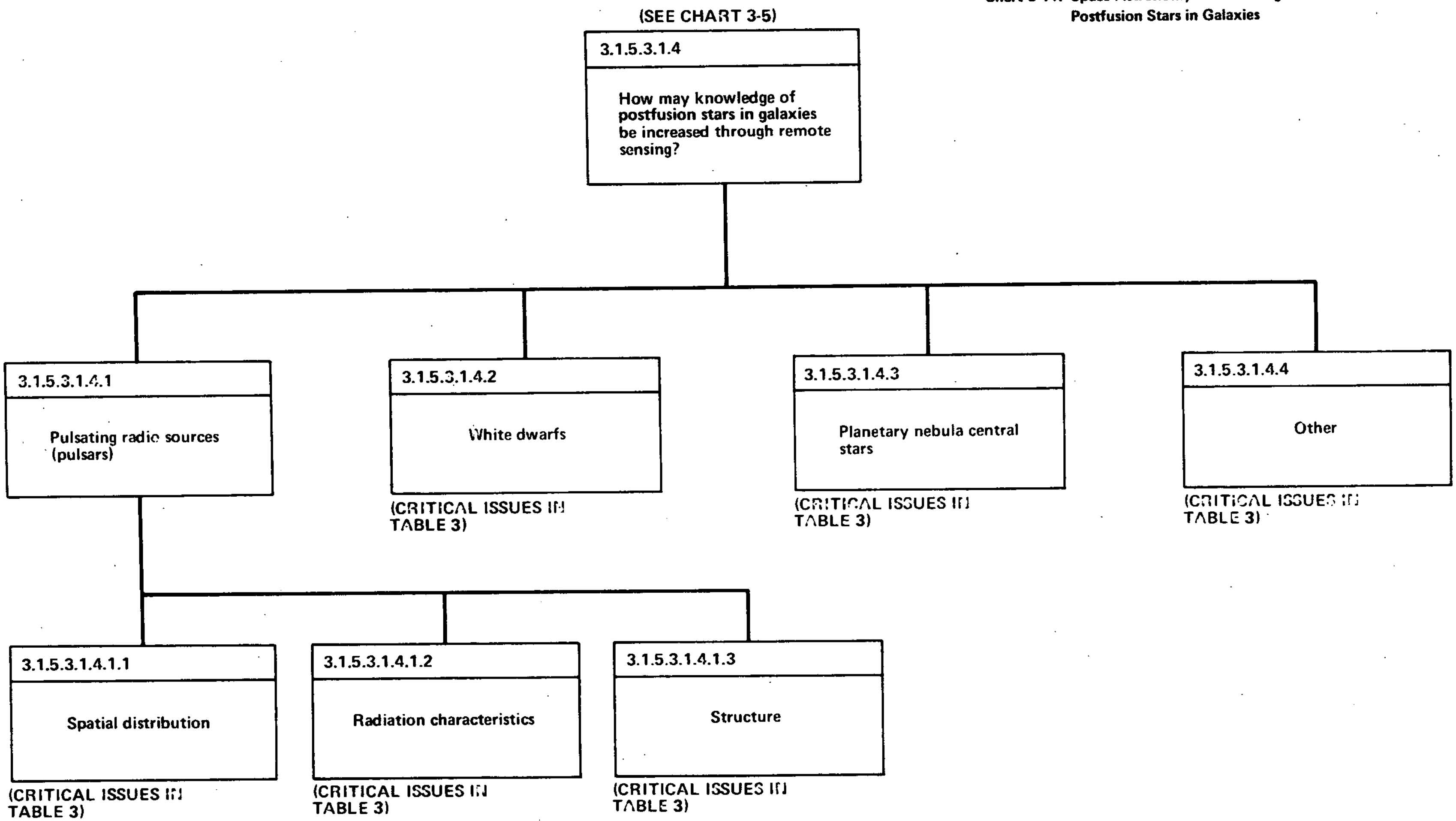
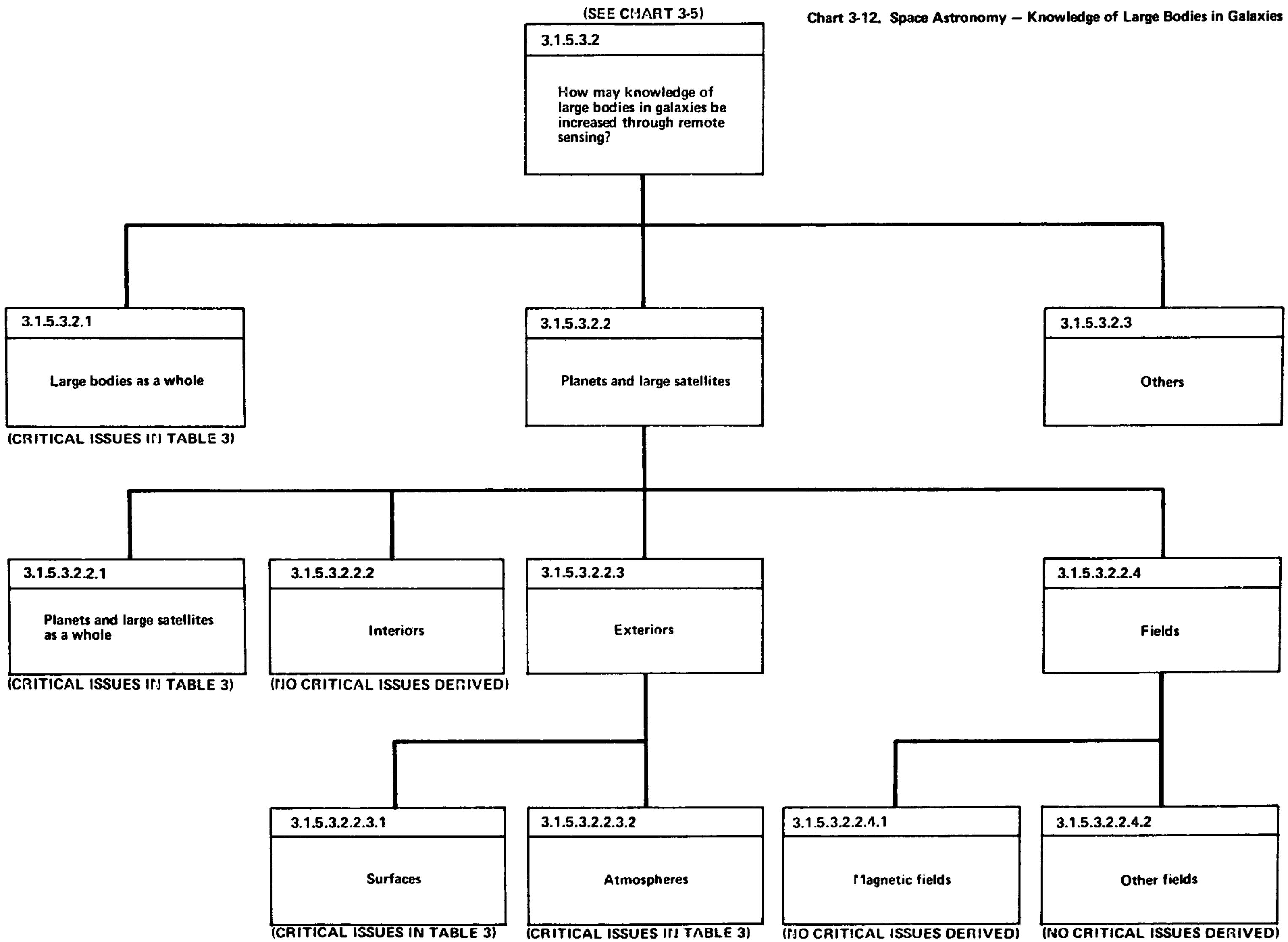


Chart 3-12. Space Astronomy – Knowledge of Large Bodies in Galaxies



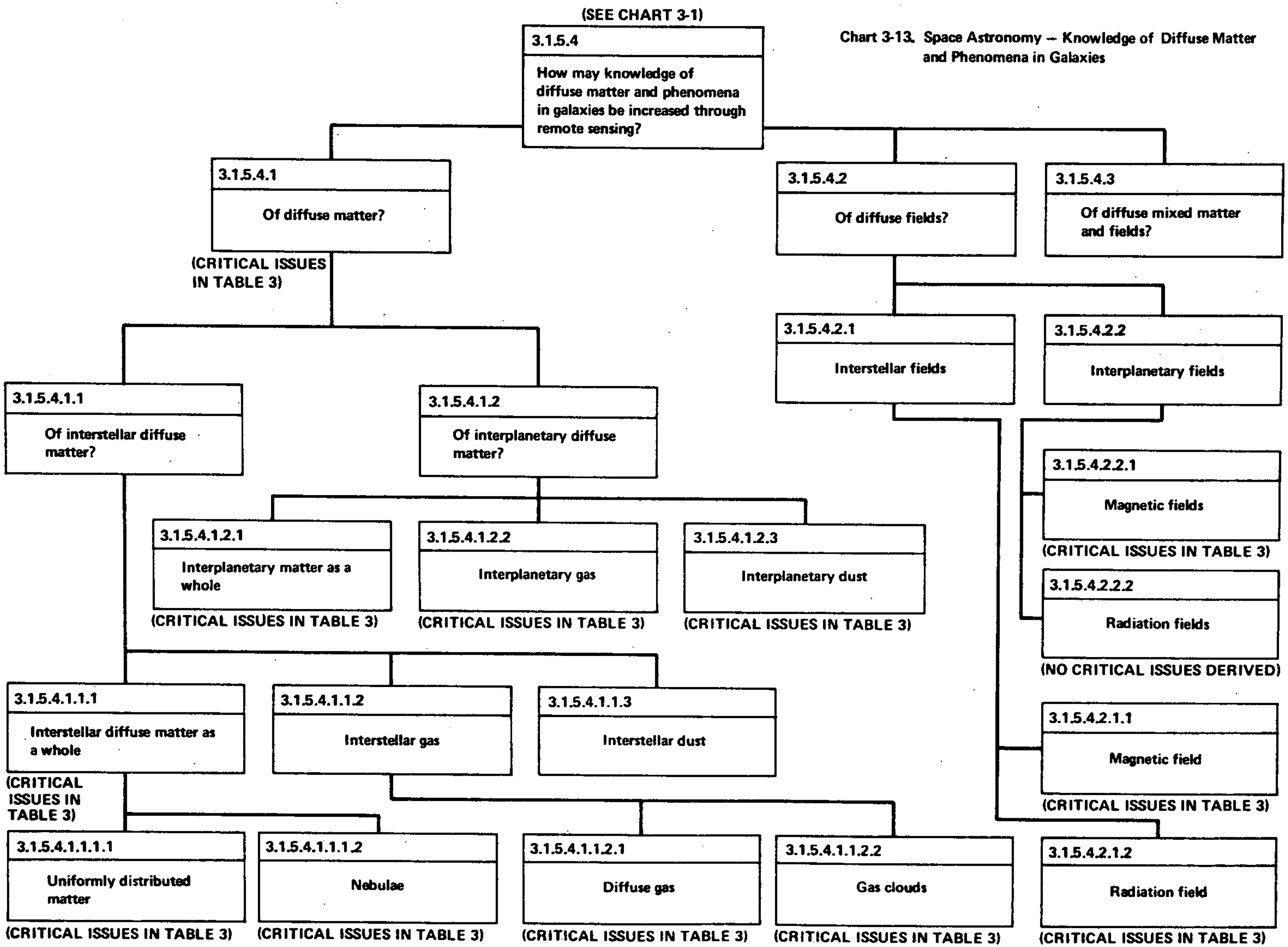


Chart 3-13. Space Astronomy – Knowledge of Diffuse Matter and Phenomena in Galaxies

Chart 3-14. Space Astronomy – Understanding of X-Ray Sources

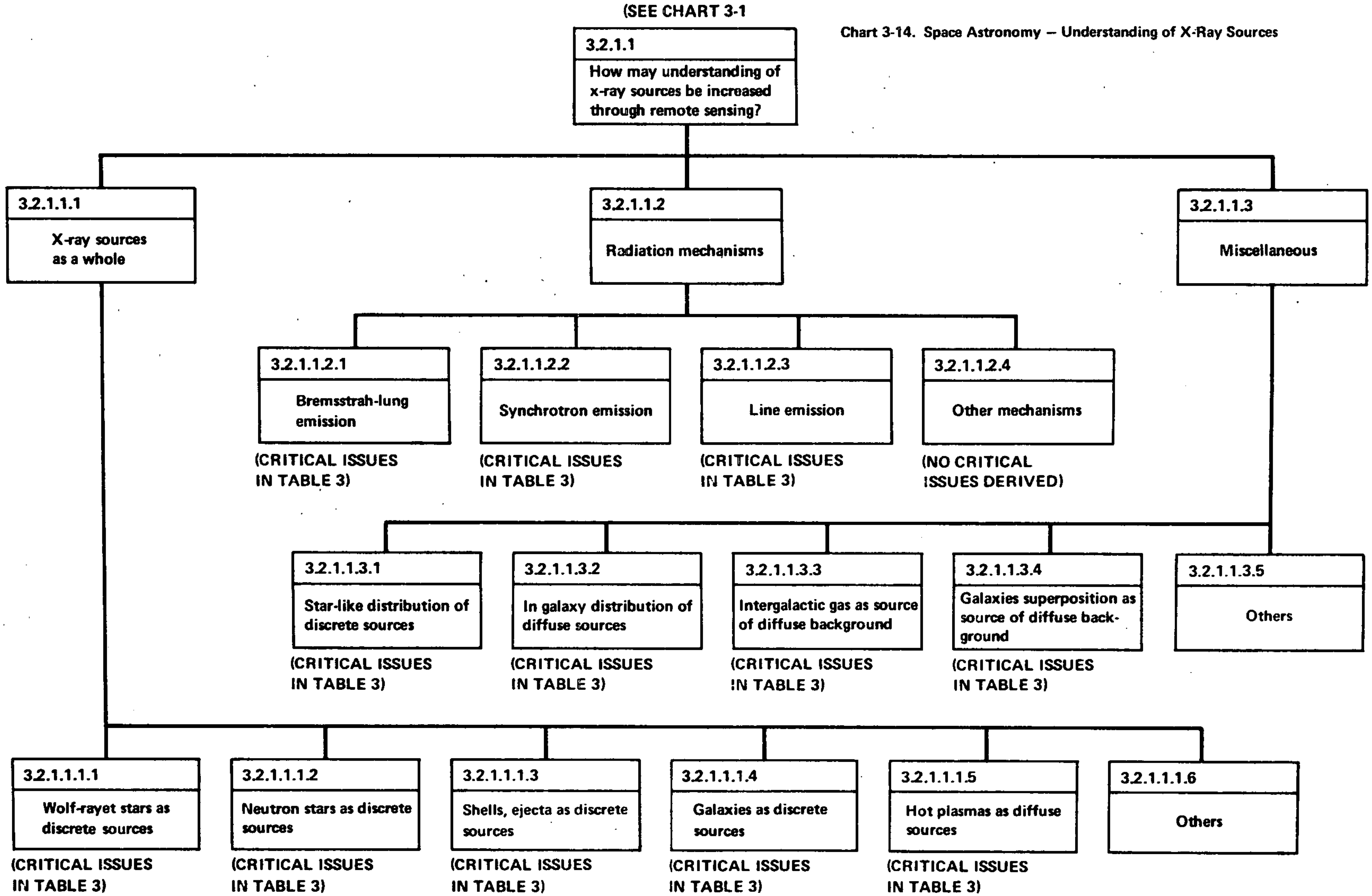


Chart 3-15. Space Astronomy – Understanding of Gamma Ray Sources

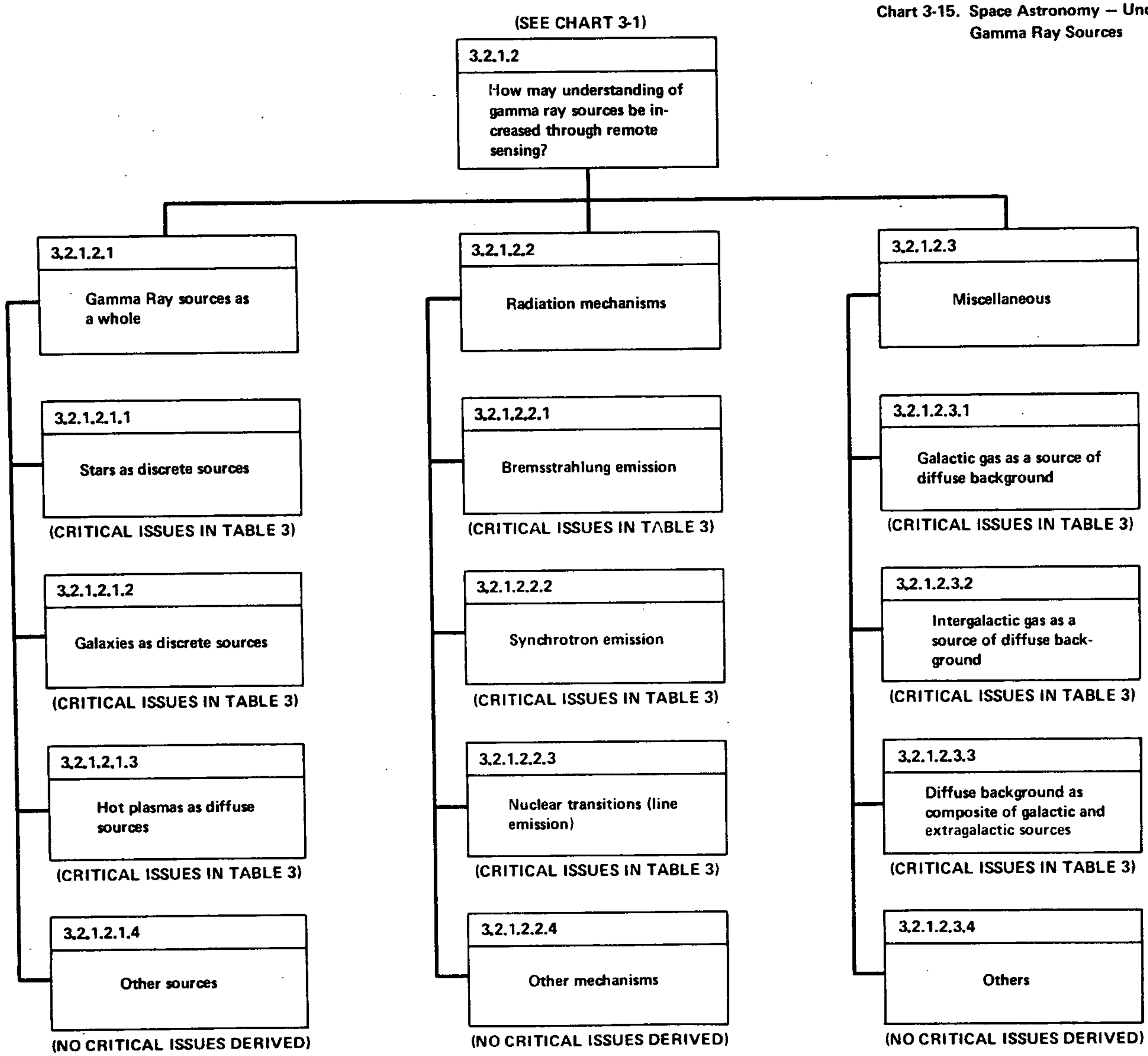


Chart 3-16. Space Astronomy – Understanding of Gravitational Radiators, Cosmic Ray Sources, and Peculiar Infrared Sources.

(SEE CHART 3-1)

3.2.1.3
How may understanding of gravitational radiators be increased through remote sensing?

- **3.2.1.3.1** Collisions or close encounters as sources
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.1.3.2** Relativistic acceleration of large masses as sources
  (NO CRITICAL ISSUES DERIVED)
- **3.2.1.3.3** Other sources
  (CRITICAL ISSUES IN TABLE 3)

(SEE CHART 3-1)

3.2.1.4
How may understanding of cosmic ray sources be increased through remote sensing?

- **3.2.1.4.1** Supernovae as sources
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.1.4.2** Normal stars as sources (e.g., flares)
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.1.4.3** Interstellar medium as an apparent source
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.1.4.4** Other sources
  (CRITICAL ISSUES IN TABLE 3)

(SEE CHART 3-1)

3.2.1.5
How may understanding of peculiar infrared sources be increased through remote sensing?

- **3.2.1.5.1** Nebulae as sources
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.1.5.2** Cool stars with dust shells as sources
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.1.5.3** Non-thermal mechanisms as sources
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.1.5.4** Line sources emission
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.1.5.5** Other sources
  (NO CRITICAL ISSUES DERIVED)

Chart 3-17. Space Astronomy – Understanding of the Universe as a Whole

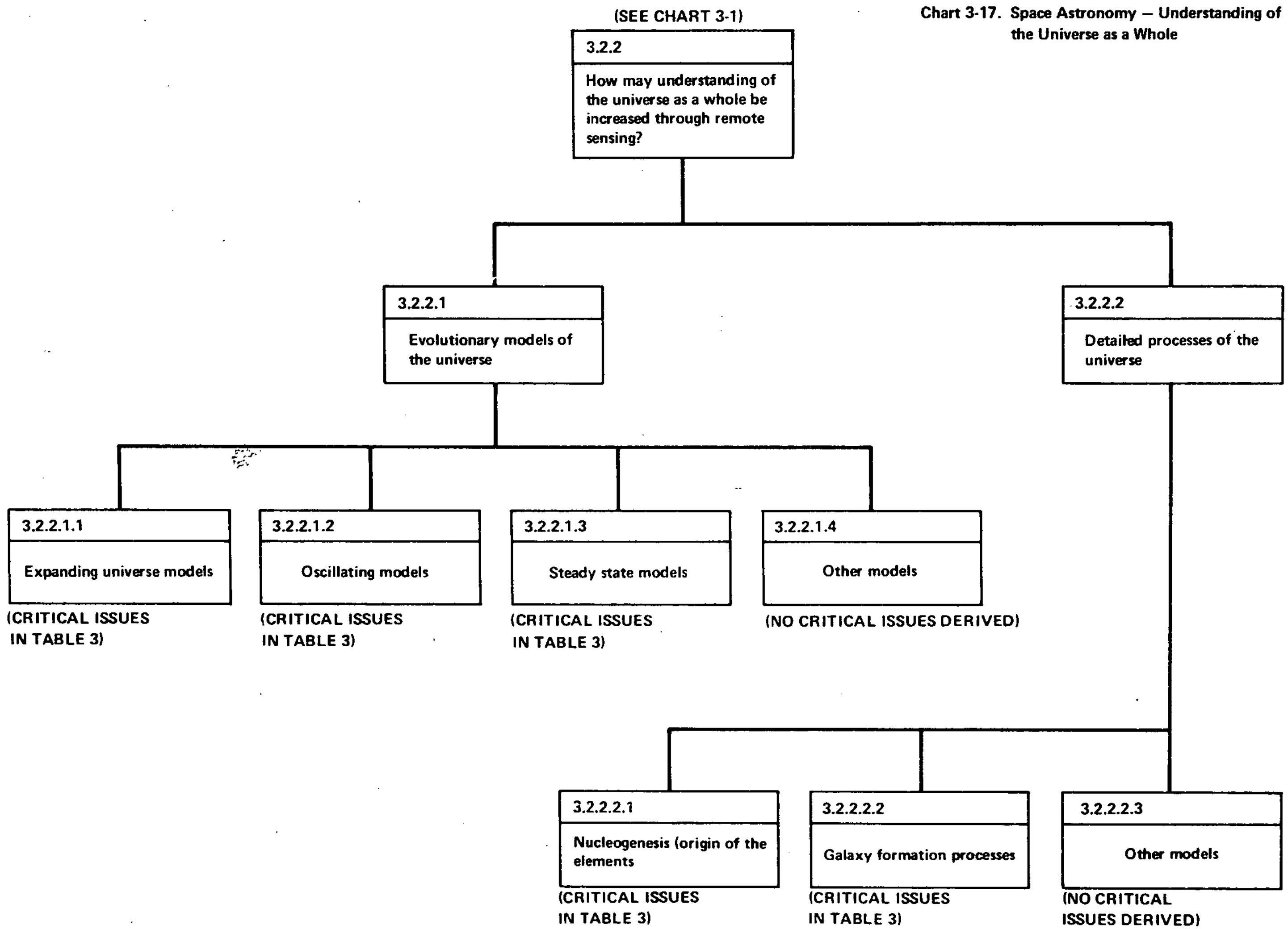


Chart 3-18. Space Astronomy – Understanding of Ensembles of Galaxies

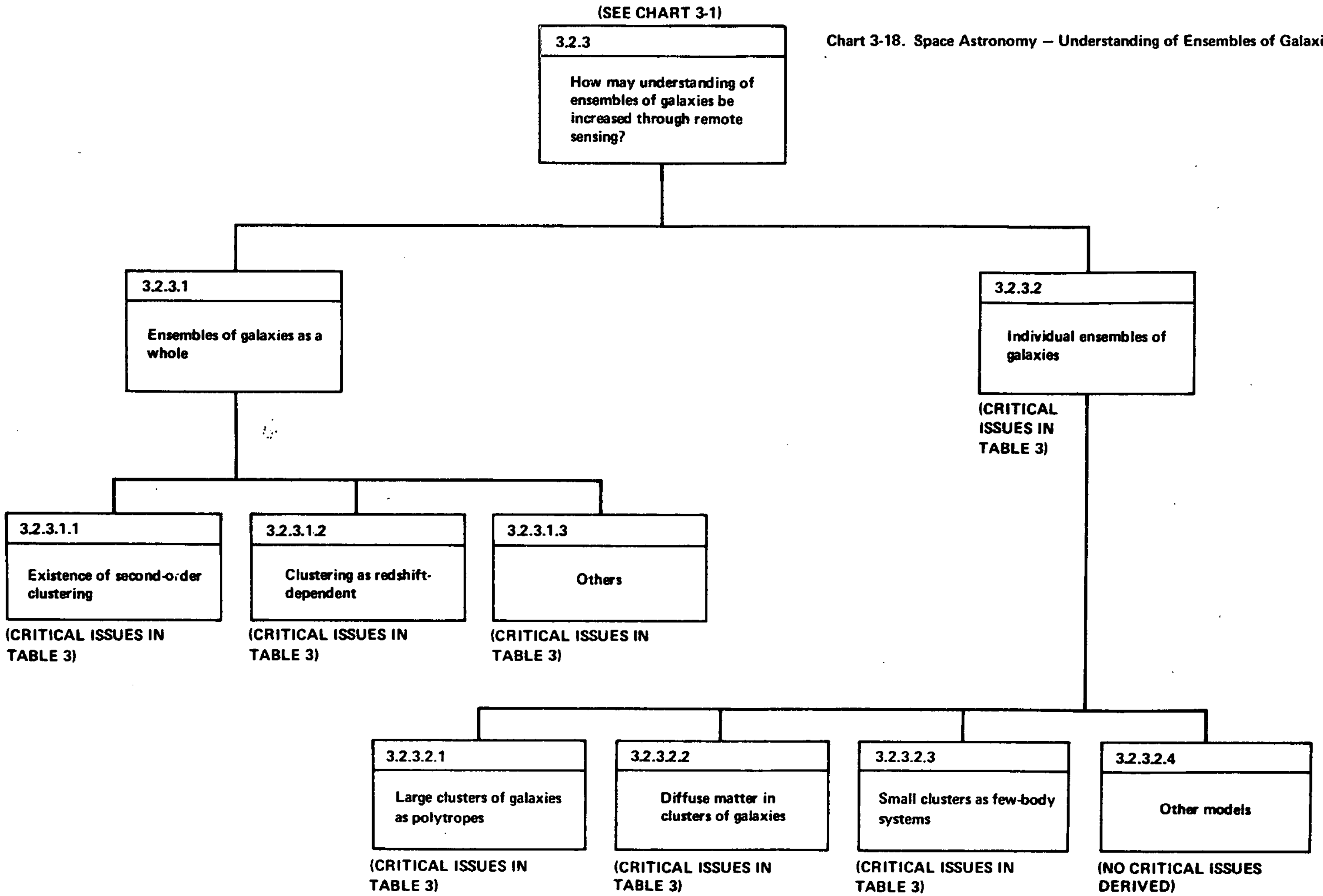
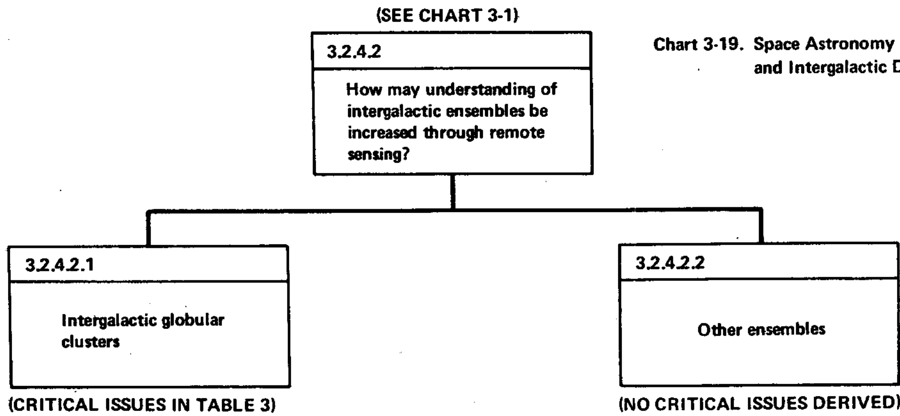


Chart 3-19. Space Astronomy — Understanding of Intergalactic Ensembles and Intergalactic Diffuse Matter or Fields



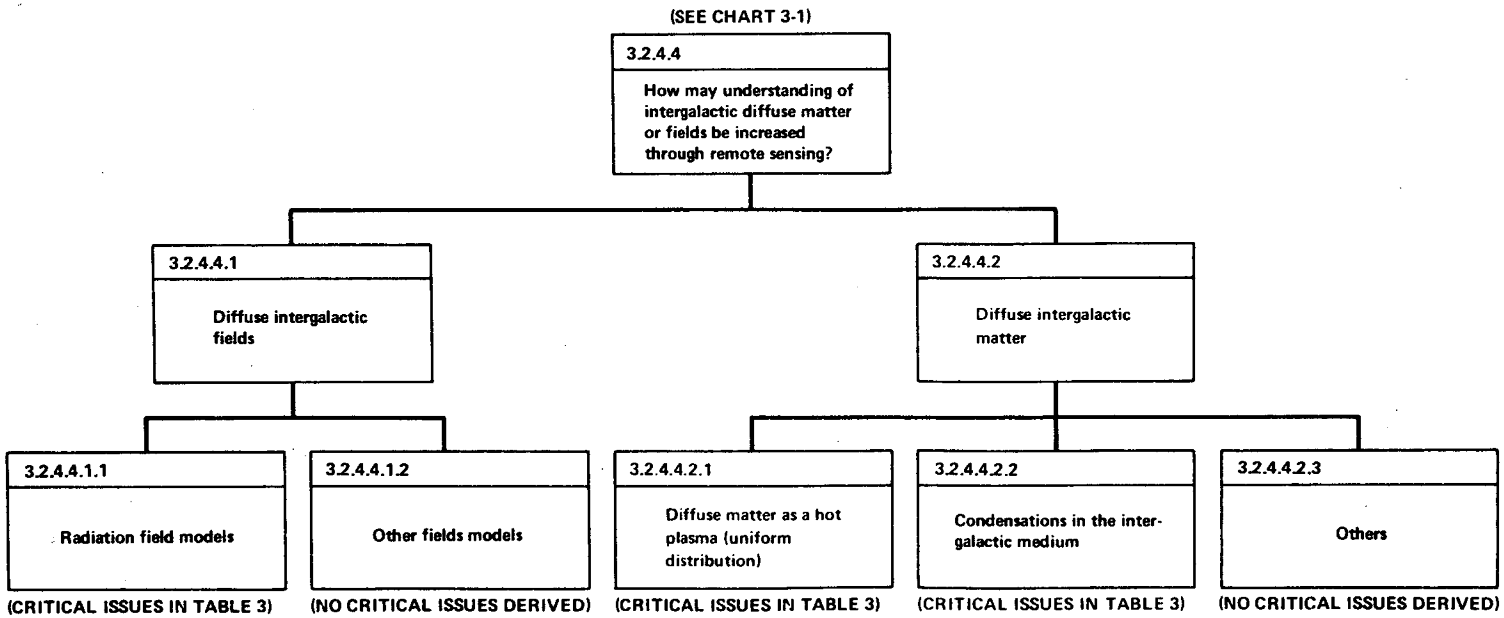


Chart 3-20. Space Astronomy – Understanding of Intergalactic Discrete Objects

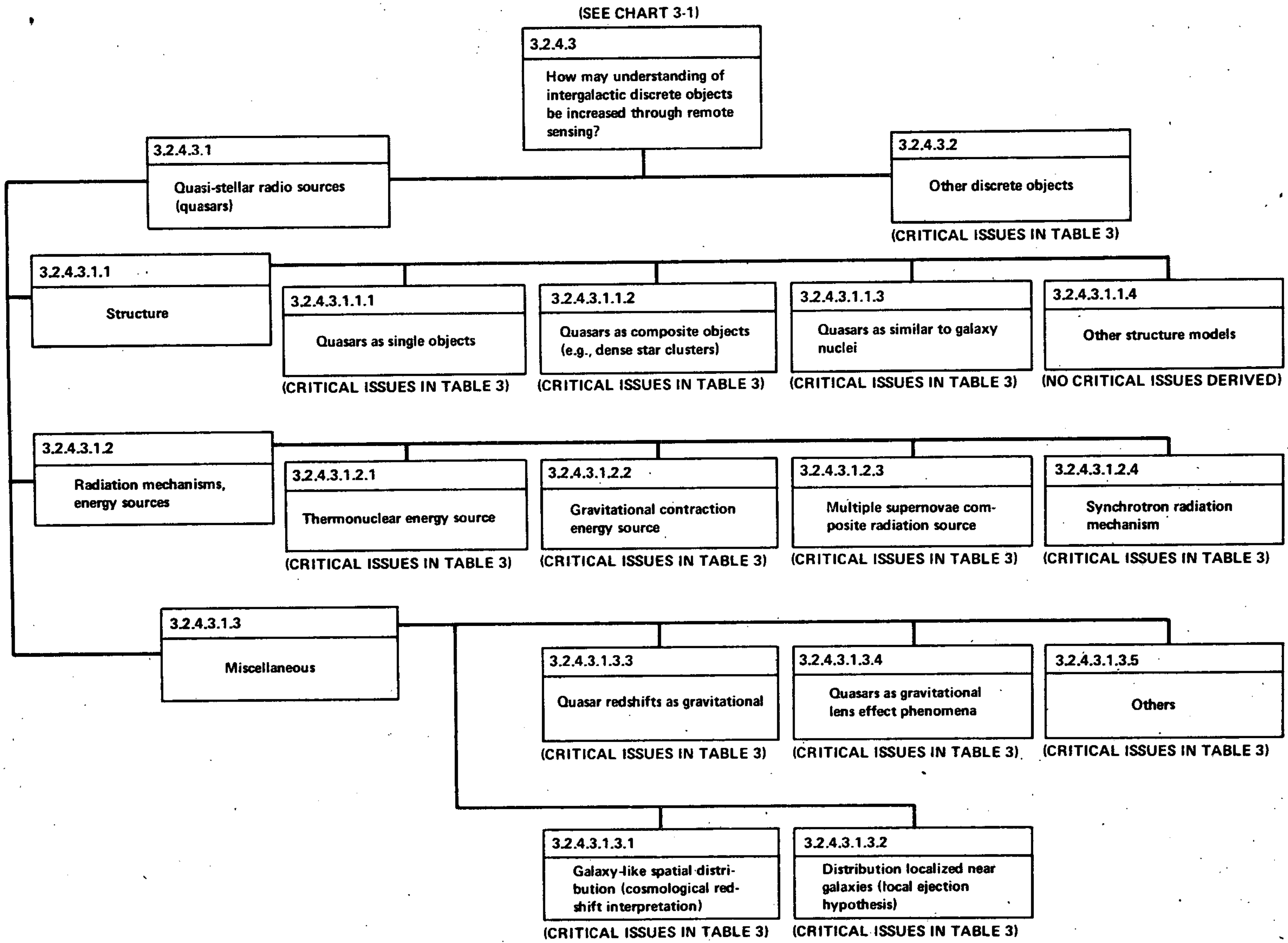


Chart 3-21. Space Astronomy – Understanding of Galaxies as a Whole

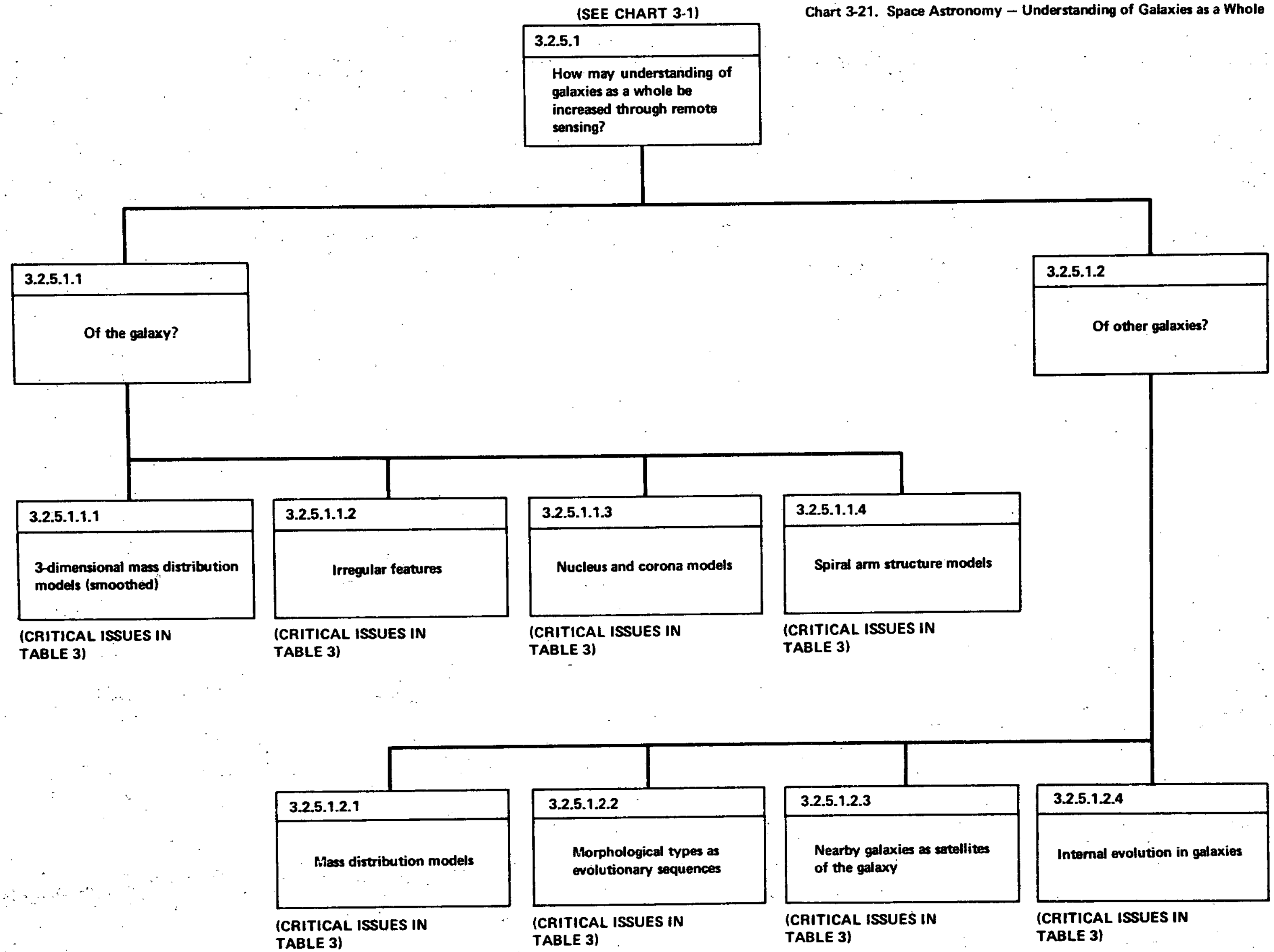
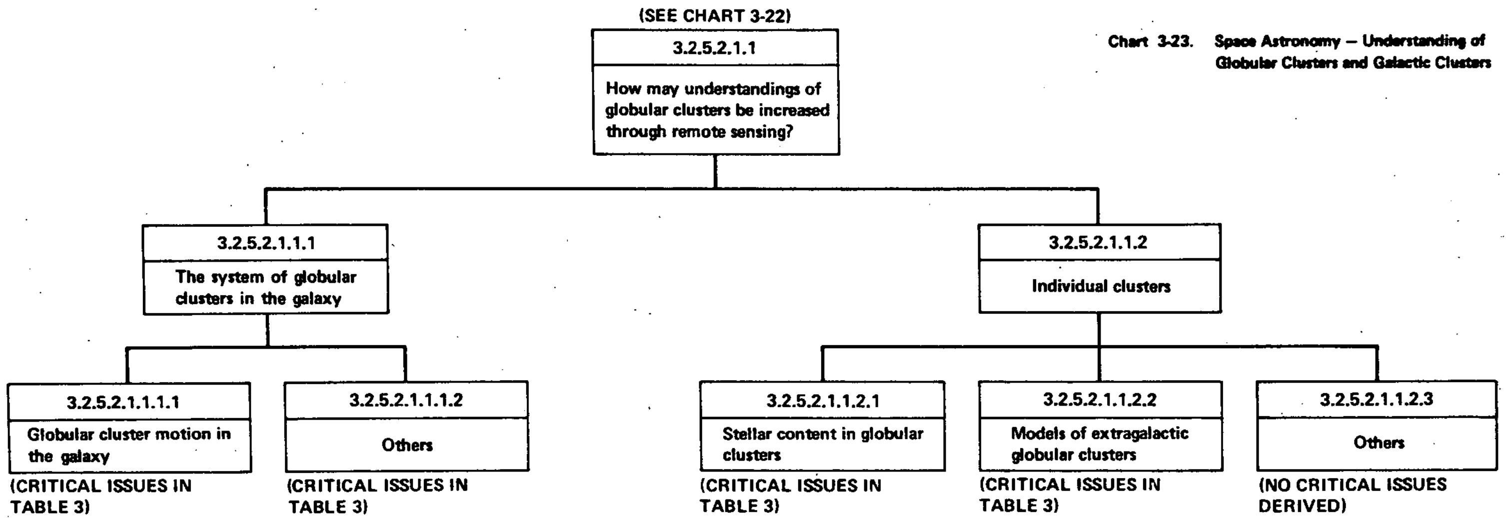


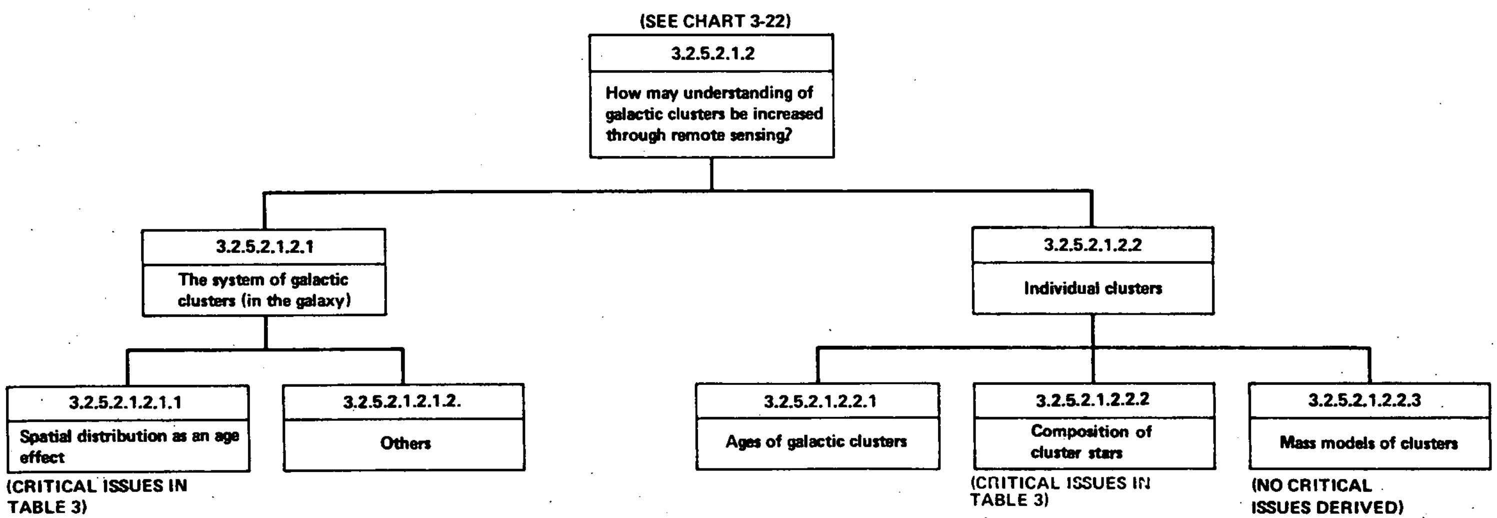
Chart 3-22. Space Astronomy – Understanding of Ensembles of Objects in Galaxies

(SEE CHART 3-1)

- **3.2.5.2** How may understanding of ensembles of objects in galaxies be increased through remote sensing?
  - **3.2.5.2.1** Of Stellar ensembles?
    - **3.2.5.2.1.1** Of globular clusters? (SEE CHART 3-23)
    - **3.2.5.2.1.2** Of galactic clusters? (SEE CHART 3-23)
    - **3.2.5.2.1.3** Of stellar assoications? (SEE CHART 3-24)
    - **3.2.5.2.1.4** Of multiple stars? (SEE CHART 3-25)
  - **3.2.5.2.2** Of solar systems?
    - **3.2.5.2.2.1** Of the solar system? (SEE CHART 3-26)
    - **3.2.5.2.2.2** Of solar systems as a whole? (NO CRITICAL ISSUES DERIVED)
    - **3.2.5.2.2.3** Of other solar systems?
      - **3.2.5.2.2.3.1** The solar system as a model for other (NO CRITICAL ISSUES DERIVED)
      - **3.2.5.2.2.3.2** Proper motion oscillations indicating planets of another solar system (CRITICAL ISSUES IN TABLE 3)
      - **3.2.5.2.2.3.3** Eclipses of dwarf stars by planets (CRITICAL ISSUES IN TABLE 3)

Chart 3-23. Space Astronomy – Understanding of Globular Clusters and Galactic Clusters





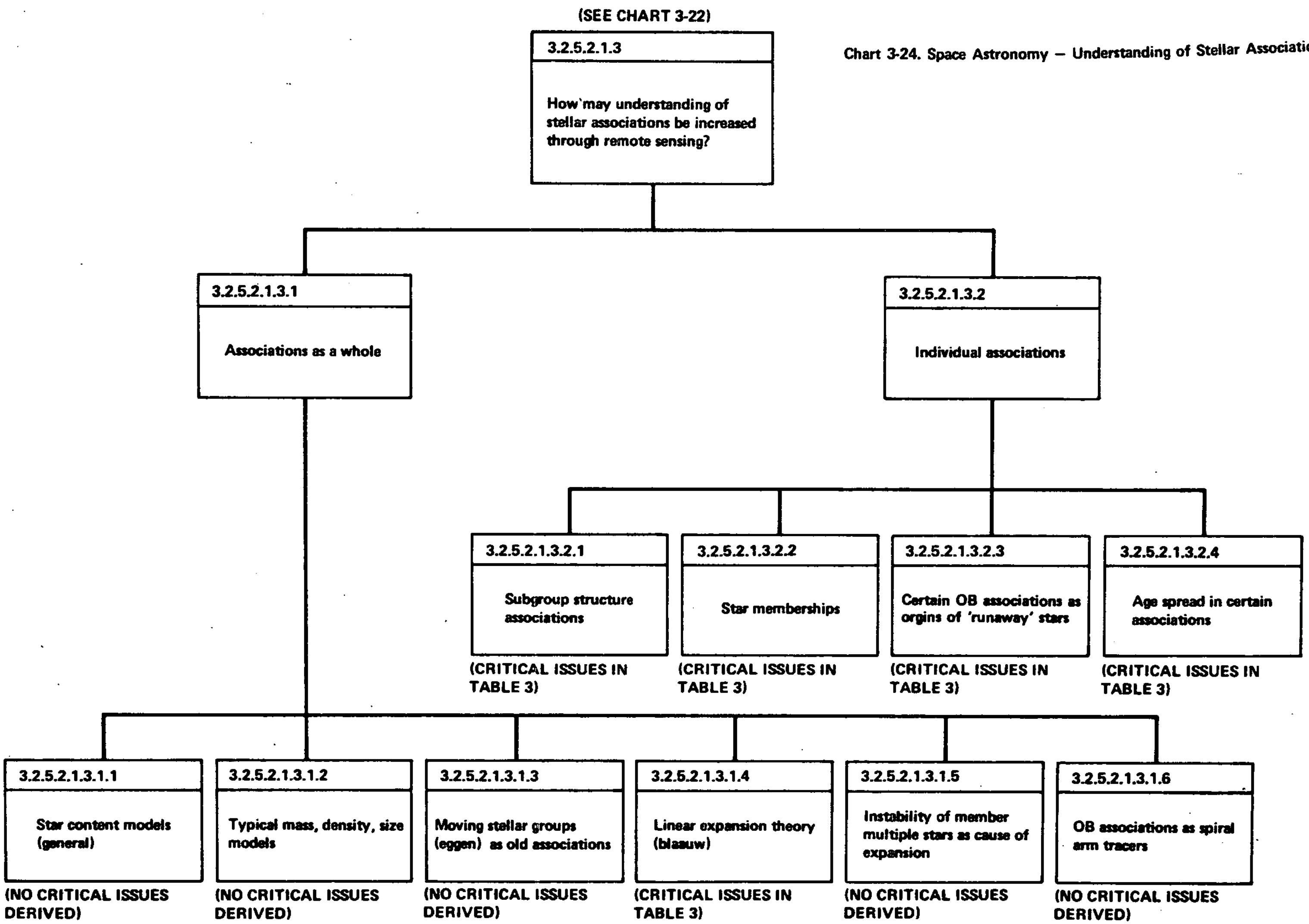


Chart 3-24. Space Astronomy – Understanding of Stellar Associations

Chart 3-25. Space Astronomy – Understanding of Multiple Stars

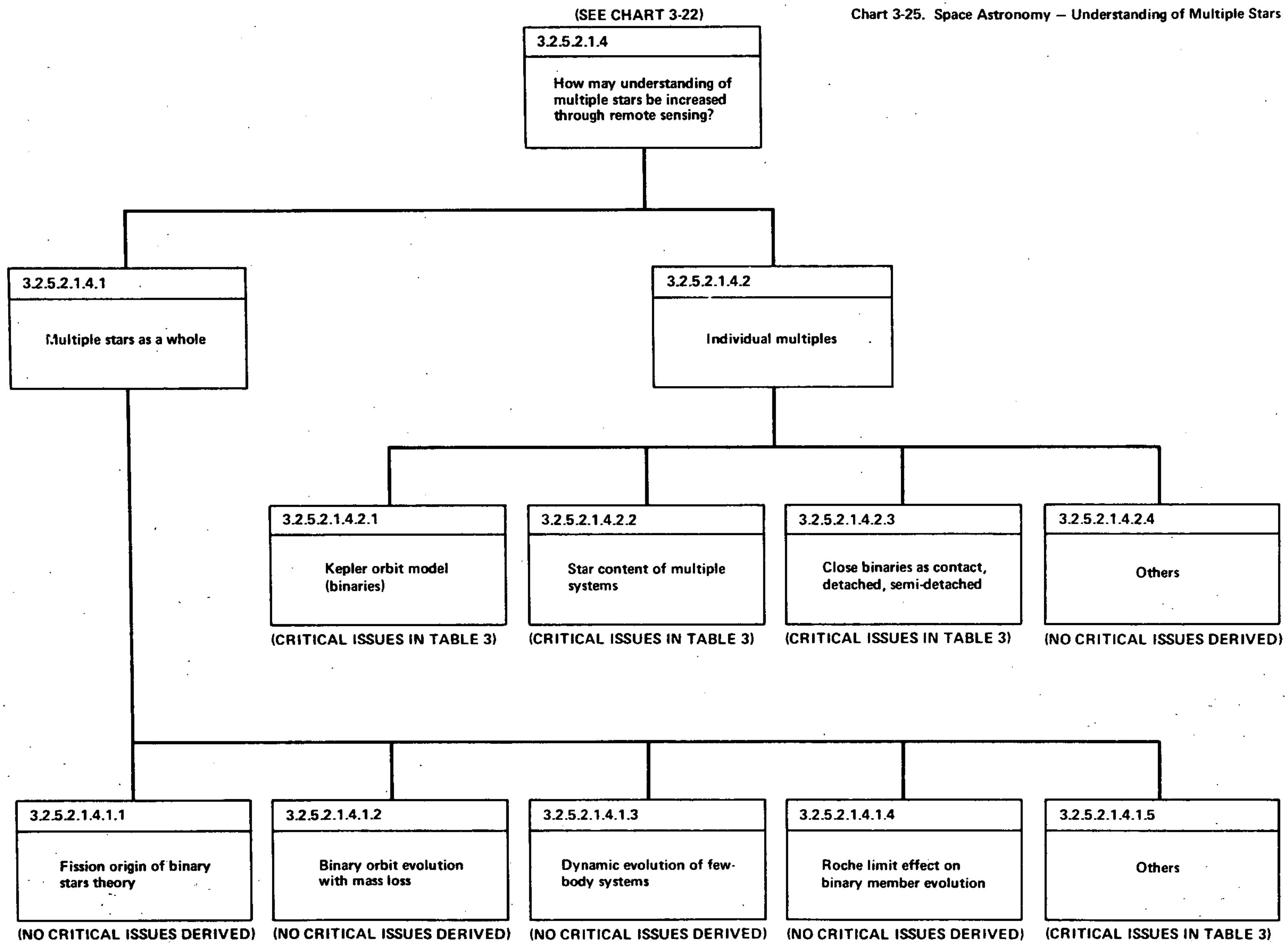


Chart 3-26. Space Astronomy – Understanding of the Solar System

(SEE CHART 3-22)

- **3.2.5.2.2.1** How may understanding the solar system be increased through remote sensing?
  - **3.2.5.2.2.1.1** The solar system as a whole
    - **3.2.5.2.2.1.1.1** Nebular origin model (CRITICAL ISSUES IN TABLE 3)
    - **3.2.5.2.2.1.1.2** Sun-star encounter origin model (NO CRITICAL ISSUES DERIVED)
    - **3.2.5.2.2.1.1.3** Planet capture origin model (CRITICAL ISSUES IN TABLE 3)
    - **3.2.5.2.2.1.1.4** Hydromagnetic braking origin (alfven) model (CRITICAL ISSUES IN TABLE 3)
    - **3.2.5.2.2.1.1.5** Sun-planet interactions (CRITICAL ISSUES IN TABLE 3)
  - **3.2.5.2.2.1.2** Comet system
    - **3.2.5.2.2.1.2.1** Comet cloud theory (oort) (NO CRITICAL ISSUES DERIVED)
    - **3.2.5.2.2.1.2.2** Planetary perturbations of comet orbits (NO CRITICAL ISSUES DERIVED)
  - **3.2.5.2.2.1.3** Asteroid system
    - **3.2.5.2.2.1.3.1** Ex-comet origin of asteroids theory (NO CRITICAL ISSUES DERIVED)
    - **3.2.5.2.2.1.3.2** Disintegrated planet origin theory (NO CRITICAL ISSUES DERIVED)
  - **3.2.5.2.2.1.4** Planet-satellite systems
    - **3.2.5.2.2.1.4.1** Saturn's ring structure evolution (CRITICAL ISSUES IN TABLE 3)
    - **3.2.5.2.2.1.4.2** Capture origin of satellites (NO CRITICAL ISSUES DERIVED)
    - **3.2.5.2.2.1.4.3** Fission origin of satellites (NO CRITICAL ISSUES DERIVED)
    - **3.2.5.2.2.1.4.4** Secular orbit changes in certain systems (CRITICAL ISSUES IN TABLE 3)
    - **3.2.5.2.2.1.4.5** Planet-satellite interactions (CRITICAL ISSUES IN TABLE 3)
  - **3.2.5.2.2.1.5** The planetary system
    - **3.2.5.2.2.1.5.1** Present state model (NO CRITICAL ISSUES DERIVED)
    - **3.2.5.2.2.1.5.2** Pluto as an escaped satellite of Neptune (CRITICAL ISSUES IN TABLE 3)
    - **3.2.5.2.2.1.5.3** Existence of a tenth planet (NO CRITICAL ISSUES DERIVED)

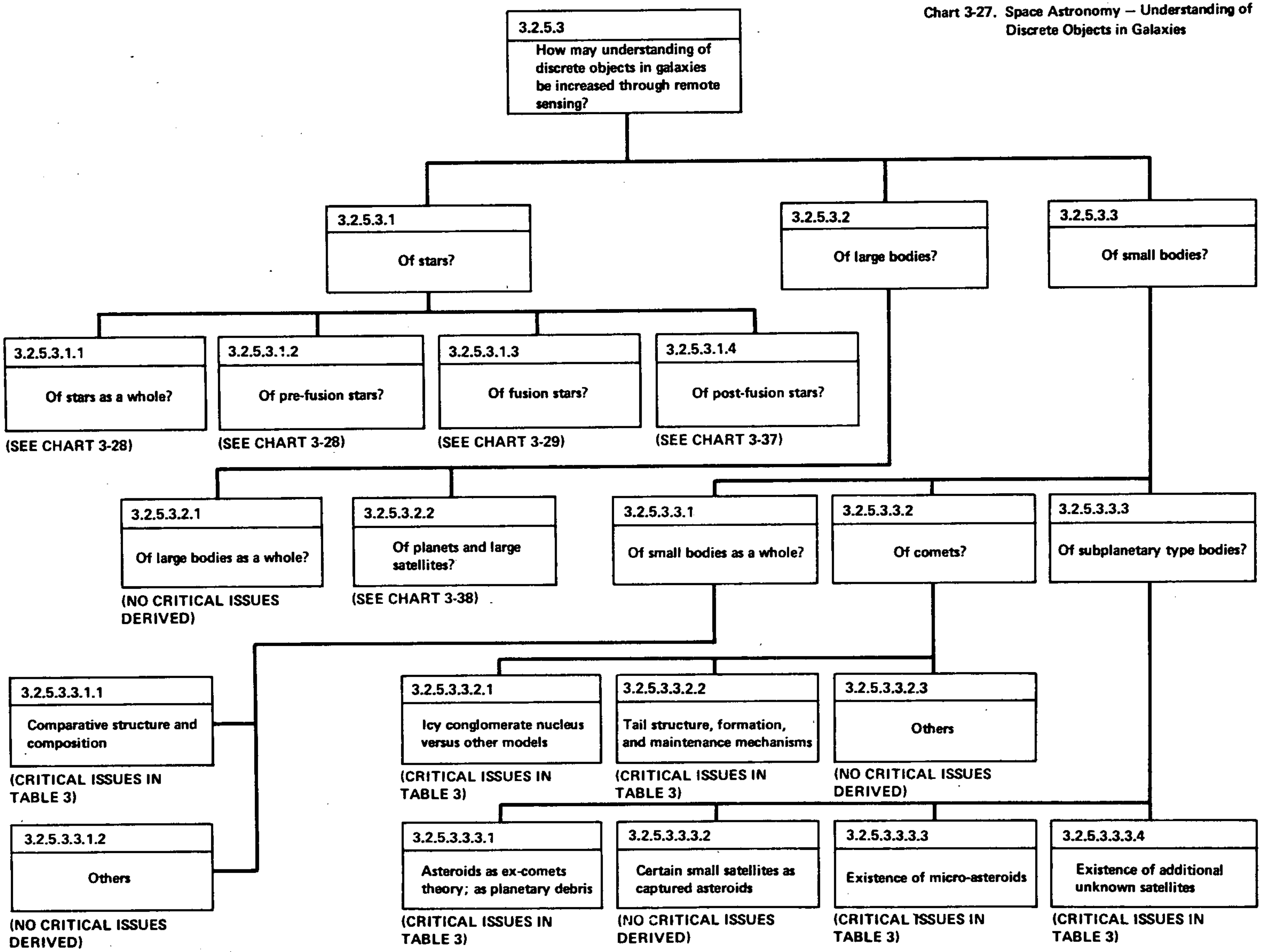


Chart 3-27. Space Astronomy – Understanding of Discrete Objects in Galaxies

Chart 3-28. Space Astronomy – Understanding of Stars as a Whole and Prefusion Stars

(SEE CHART 3-27)

3.2.5.3.1.1 How may understanding of stars as a whole be increased through remote sensing?

- **3.2.5.3.1.1.1** Theory of normal stellar evolution (CRITICAL ISSUES IN TABLE 3)
- **3.2.5.3.1.1.2** Significance of mass loss (CRITICAL ISSUES IN TABLE 3)
- **3.2.5.3.1.1.3** Effect of rotation on evolution (CRITICAL ISSUES IN TABLE 3)
- **3.2.5.3.1.1.4** Existence of a limiting stellar mass (CRITICAL ISSUES IN TABLE 3)

(SEE CHART 3-27)

3.2.5.3.1.2 How may understanding of prefusion stars be increased through remote sensing?

- **3.2.5.3.1.2.1** T Tauri star models (CRITICAL ISSUES IN TABLE 3)
- **3.2.5.3.1.2.2** Wolf-Rayet stars as premain sequence objects (CRITICAL ISSUES IN TABLE 3)
- **3.2.5.3.1.2.3** Faintest M-type dwarfs as prefusion objects (CRITICAL ISSUES IN TABLE 3)
- **3.2.5.3.1.2.4** Differential-rate dynamic collapse models (NO CRITICAL ISSUES DERIVED)
- **3.2.5.3.1.2.5** Dynamic collapse with magnetic field, rotation, models (NO CRITICAL ISSUES DERIVED)

Chart 3-29. Space Astronomy — Understanding of Fusion Stars

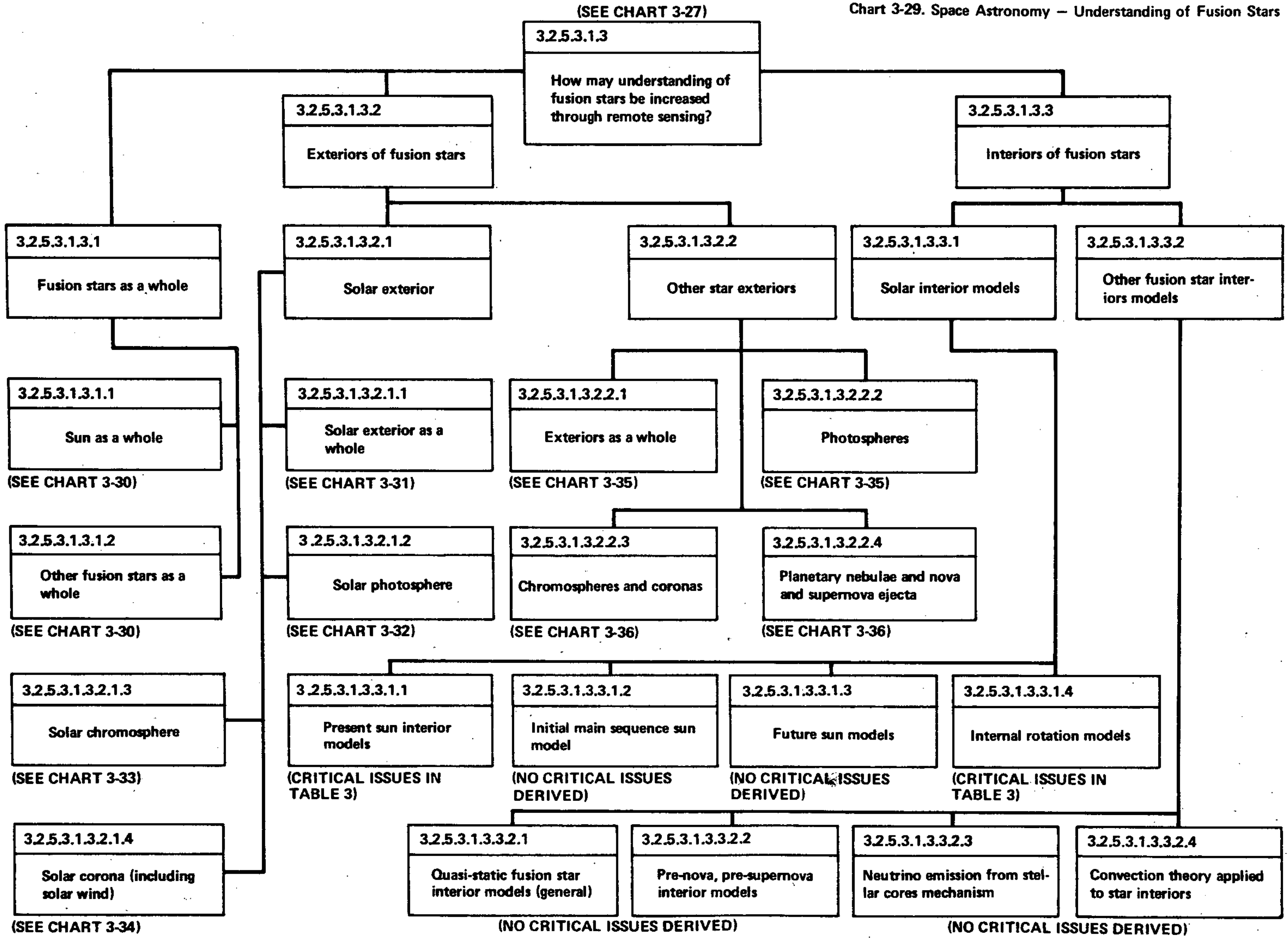


Chart 3-30. Space Astronomy — Understanding of the Sun as a Whole and Other Fusion Stars as a Whole

(SEE CHART 3-29)

3.2.5.3.1.3.1.1
How may understanding of sun as a whole be increased through remote sensing?

- **3.2.5.3.1.3.1.1.1** — Solar cycle origin and maintenance models
  (NO CRITICAL ISSUES DERIVED)
- **3.2.5.3.1.3.1.1.2** — Solar differential rotation models
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.5.3.1.3.1.1.3** — Solar magnetic field models
  (CRITICAL ISSUES IN TABLE 3)

(SEE CHART 3-29)

3.2.5.3.1.3.1.2
How may understanding of other fusion stars as a whole be increased through remote sensing?

- **3.2.5.3.1.3.1.2.1** — Fusion star models (quasistatic)
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.5.3.1.3.1.2.2** — Pulsating star models
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.5.3.1.3.1.2.3** — Magnetic and rapidly rotating star models
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.5.3.1.3.1.2.4** — Effect of mass loss
  (CRITICAL ISSUES IN TABLE 3)

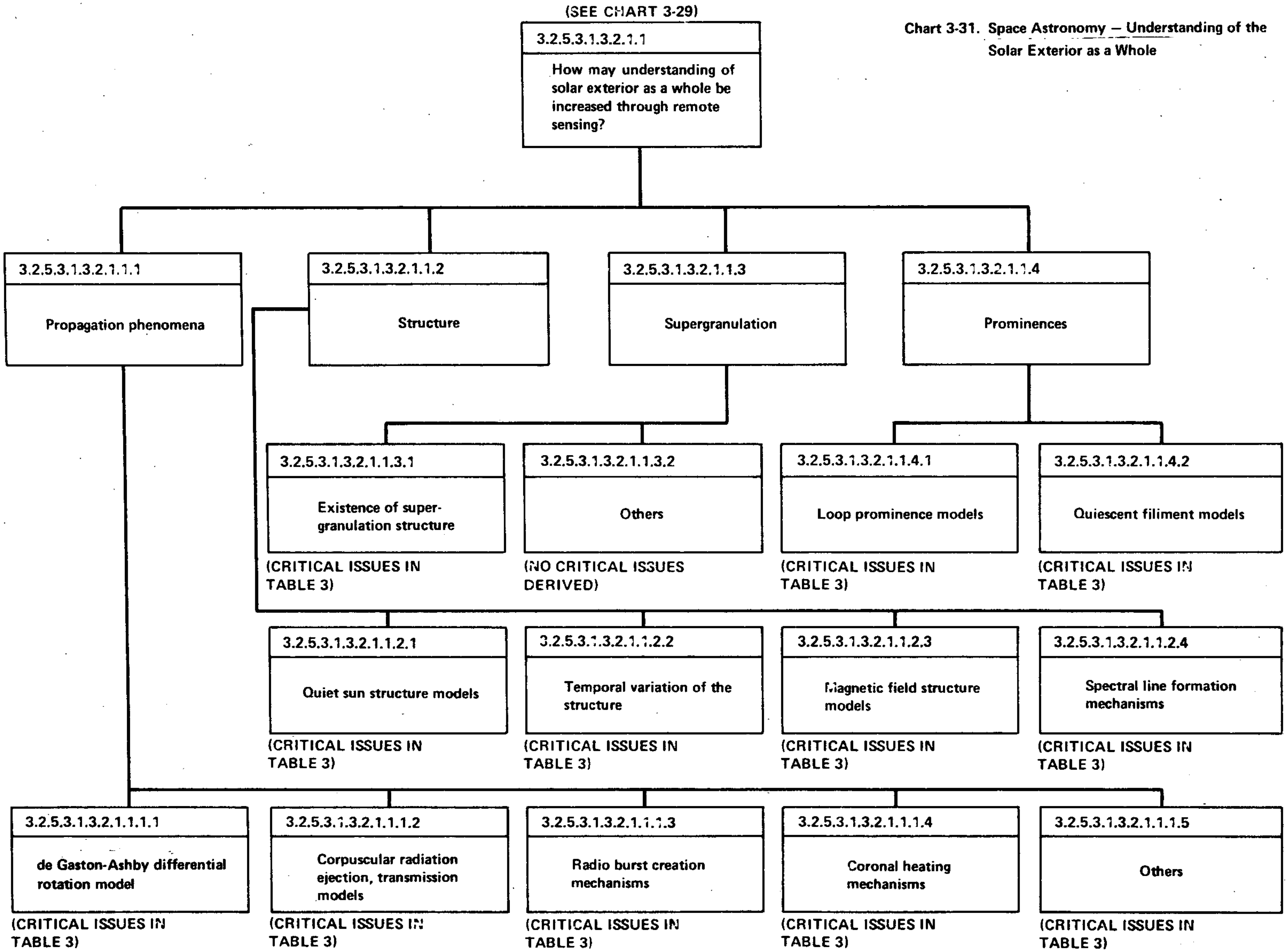


Chart 3-31. Space Astronomy – Understanding of the Solar Exterior as a Whole

Chart 3-32. Space Astronomy – Understanding of the Solar Photosphere

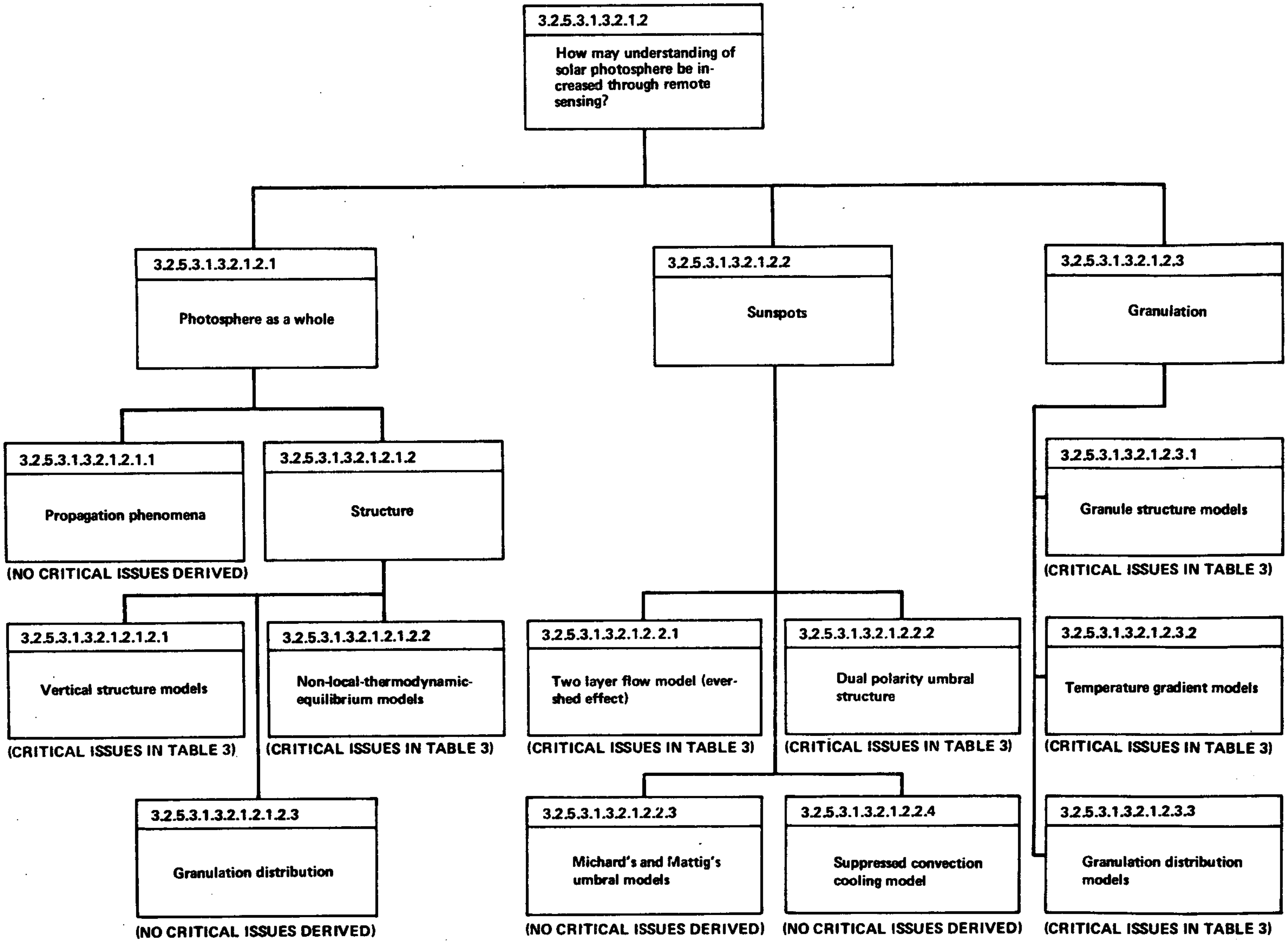


Chart 3-33. Space Astronomy — Understanding of the Solar Chromosphere

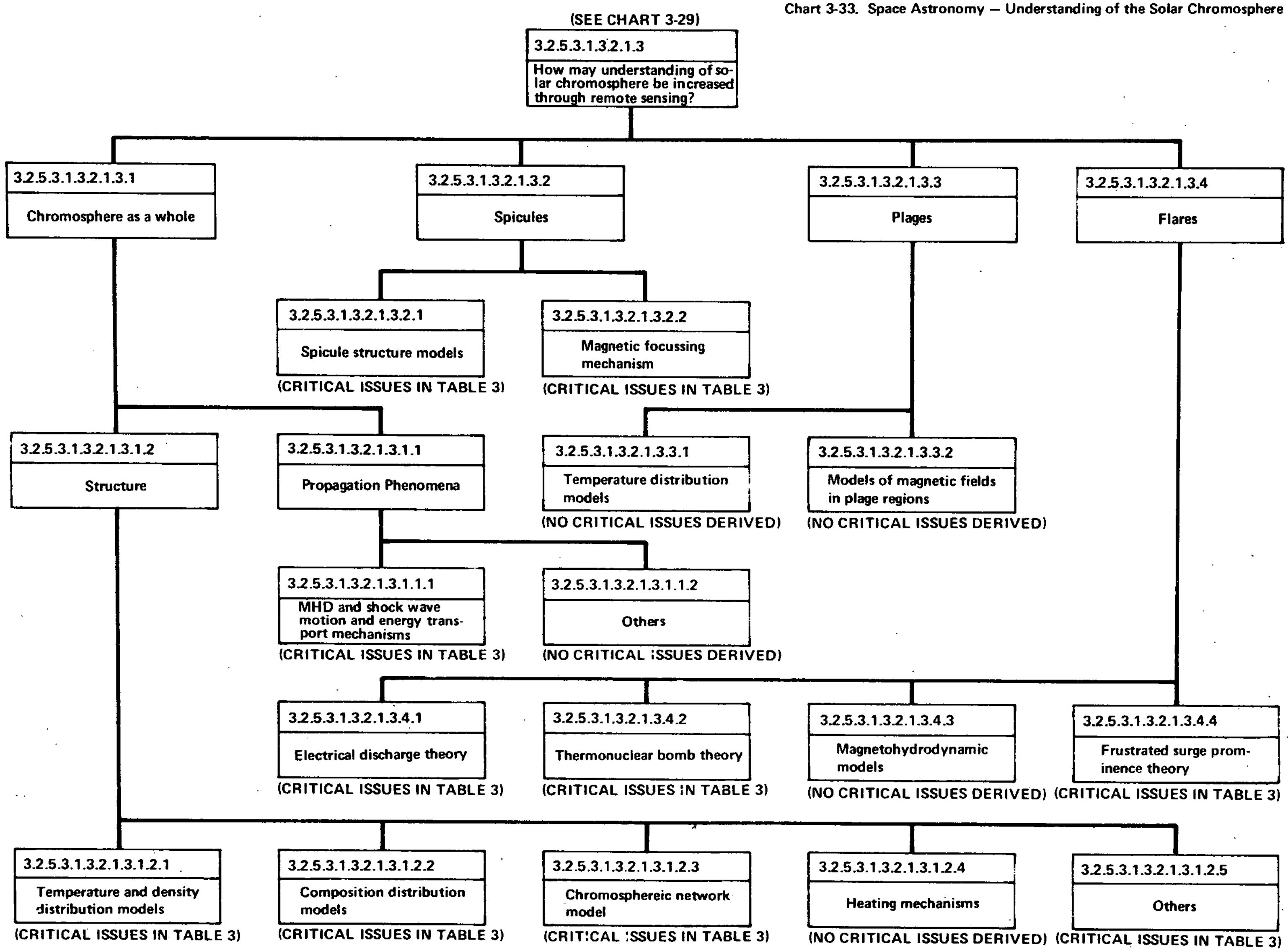


Chart 3-34. Space Astronomy – Understanding of the Solar Corona (Including Solar Wind)

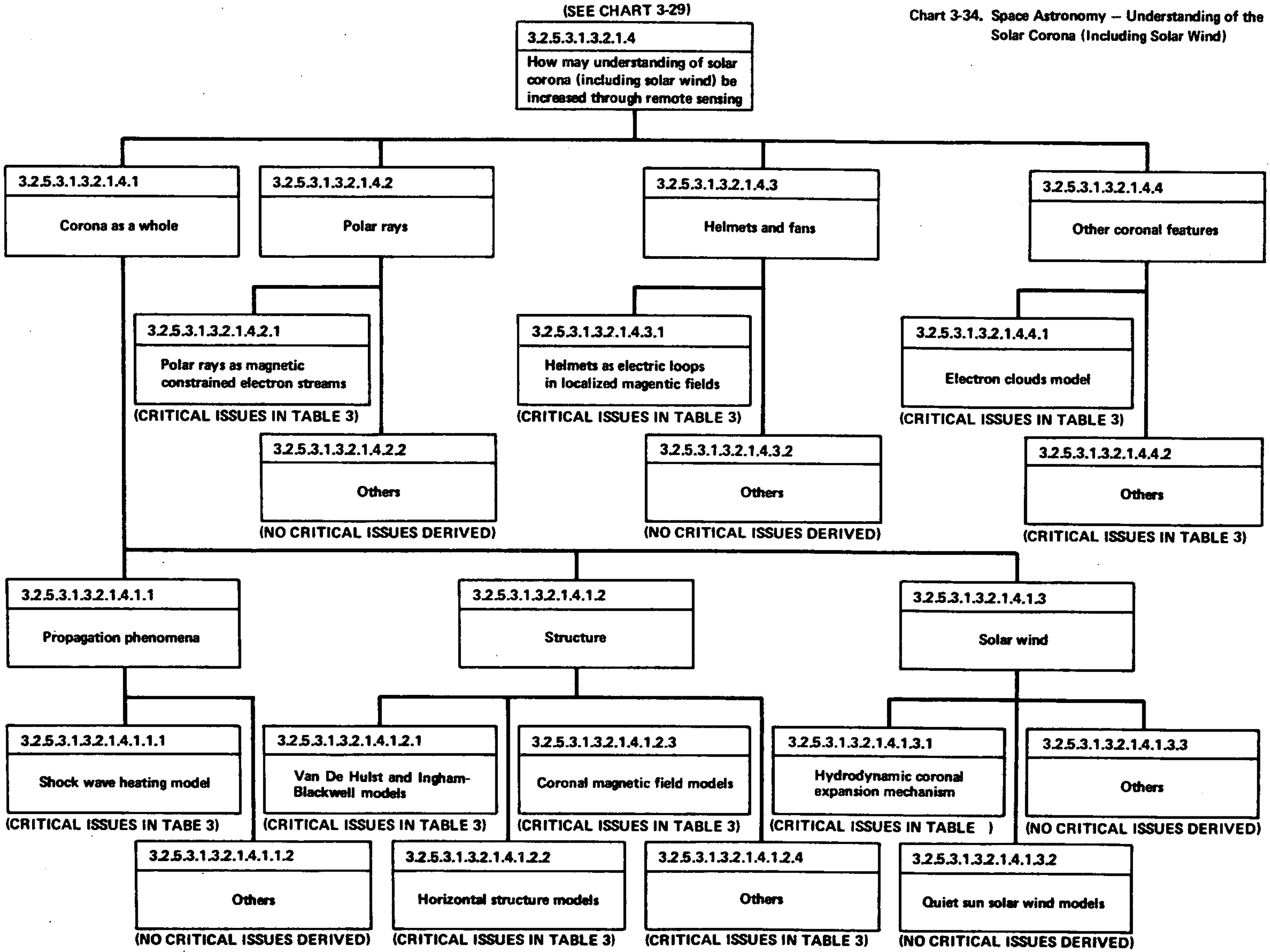


Chart 3-35. Space Astronomy – Understanding of Exteriors of Fusion Stars as a Whole and of Photospheres of Fusion Stars

(SEE CHART 3-29)

- **3.2.5.3.1.3.2.2.1** How may understanding of exteriors of fusion stars as a whole be increased through remote sensing?
  - **3.2.5.3.1.3.2.2.1.1** Brightness fluctuations of certain dwarf stars as "flares"
    (CRITICAL ISSUES IN TABLE 3)
  - **3.2.5.3.1.3.2.2.1.2** Energy transfer mechanisms in stellar atmospheres
    (NO CRITICAL ISSUES DERIVED)
  - **3.2.5.3.1.3.2.2.1.3** Typical compositions: Pop I, Pop II, peculiar stars
    (NO CRITICAL ISSUES DERIVED)
  - **3.2.5.3.1.3.2.2.1.4** Others
    (CRITICAL ISSUES IN TABLE 3)

(SEE CHART 3-29)

- **3.2.5.3.1.3.2.2.2** How may understanding of photospheres of fusion stars be increased through remote sensing?
  - **3.2.5.3.1.3.2.2.2.1** Photospheres models (general)
    (NO CRITICAL ISSUES DERIVED)
  - **3.2.5.3.1.3.2.2.2.2** Non-lte in stellar atmospheres
    (NO CRITICAL ISSUES DERIVED)
  - **3.2.5.3.1.3.2.2.2.3** Line absorption effects on structure
    (NO CRITICAL ISSUES DERIVED)

Chart 3-36. Space Astronomy – Understanding of Chromospheres, Coronas, Planetary Nebulae, and Nova and Supernova Ejecta of Fusion Stars

(SEE CHART 3-29)

3.2.5.3.1.3.2.2.3

How may understanding of chromospheres and coronas of fusion stars be increased through remote sensing?

- **3.2.5.3.1.3.2.2.3.1** — Hot chromosphere models (late-type stars)
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.5.3.1.3.2.2.3.2** — Stellar "winds" or expanding "coronas" models
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.5.3.1.3.2.2.3.3** — Circumstellar dust shells models
  (NO CRITICAL ISSUES DERIVED)
- **3.2.5.3.1.3.2.2.3.4** — Emission mechanisms
  (NO CRITICAL ISSUES DERIVED)

(SEE CHART 3-29)

3.2.5.3.1.3.2.2.4

How may understanding of planetary nebulae and nova and supernova ejecta be increased through remote sensing?

- **3.2.5.3.1.3.2.2.4.1** — 3-dimensional models of planetary nebulae (smoothed)
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.5.3.1.3.2.2.4.2** — Fine structure (inhomogeneities, asymmetries) in planetary nebulae.
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.5.3.1.3.2.2.4.3** — Nova and supernova shell models
  (CRITICAL ISSUES IN TABLE 3)
- **3.2.5.3.1.3.2.2.4.4** — Shell interaction with interstellar matter mechanisms
  (NO CRITICAL ISSUES DERIVED)

Chart 3-37. Space Astronomy – Understanding of Postfusion Stars

(SEE CHART 3-27)

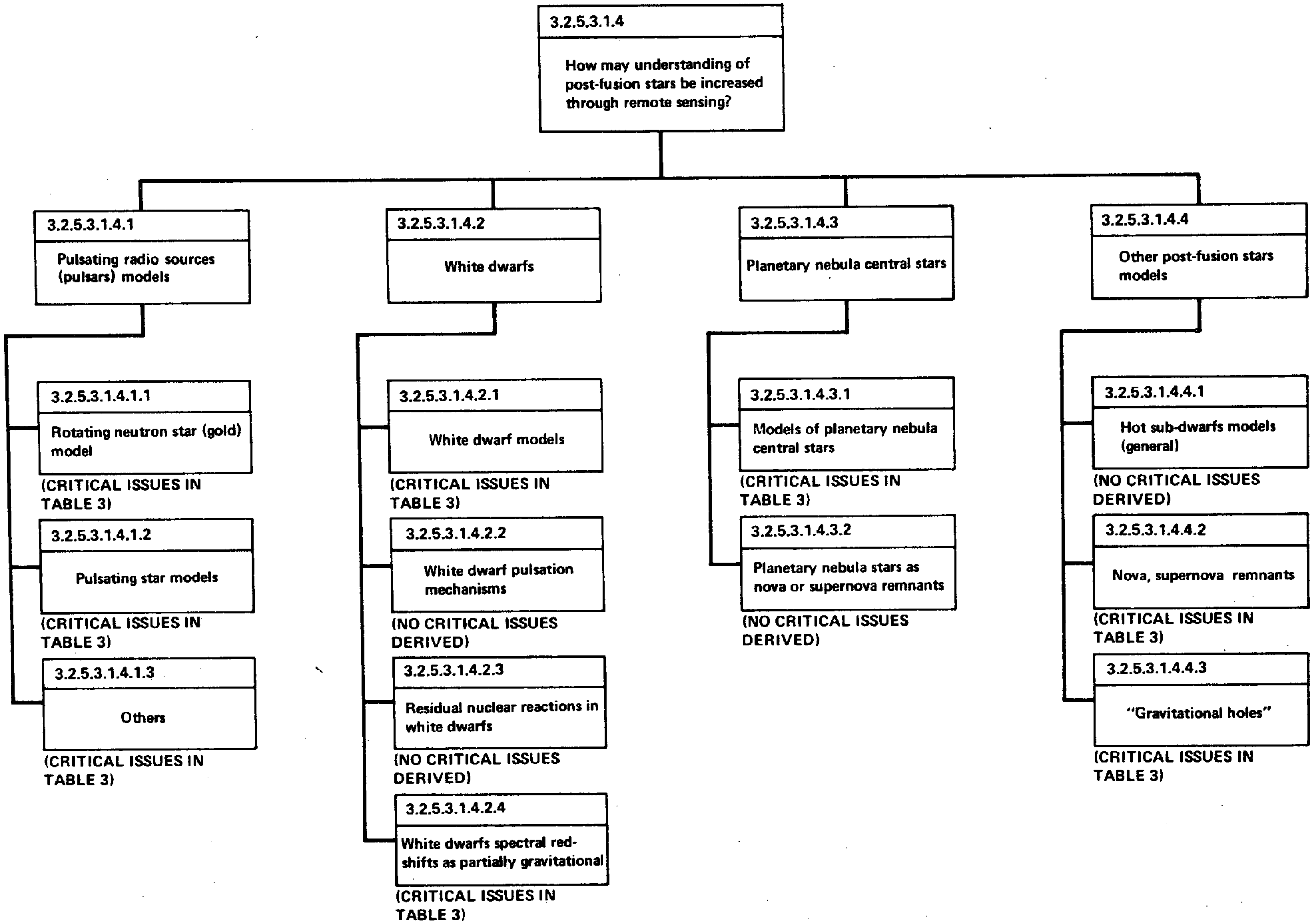


Chart 3-38. Space Astronomy – Understanding of Planets and Large Satellites

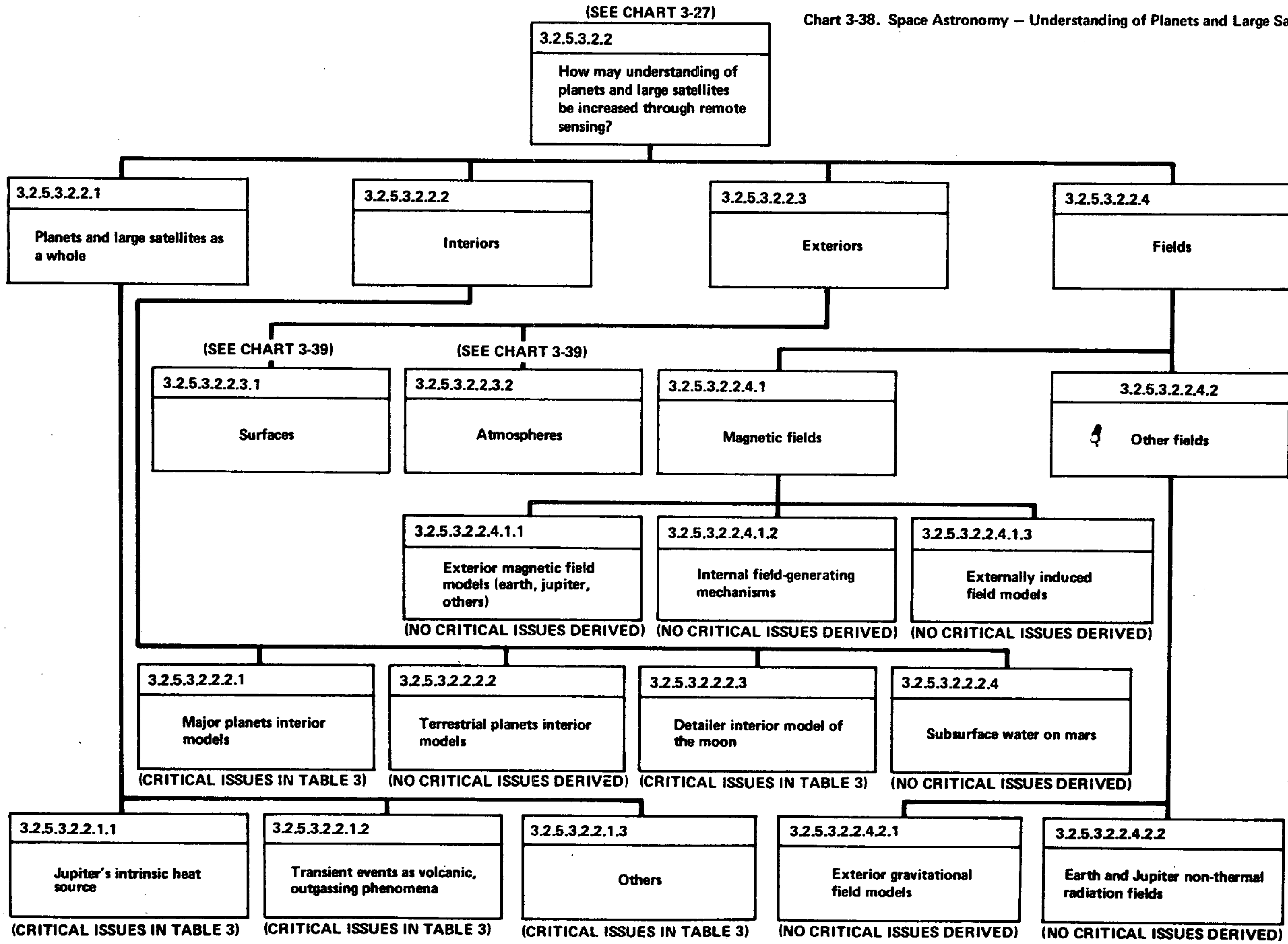
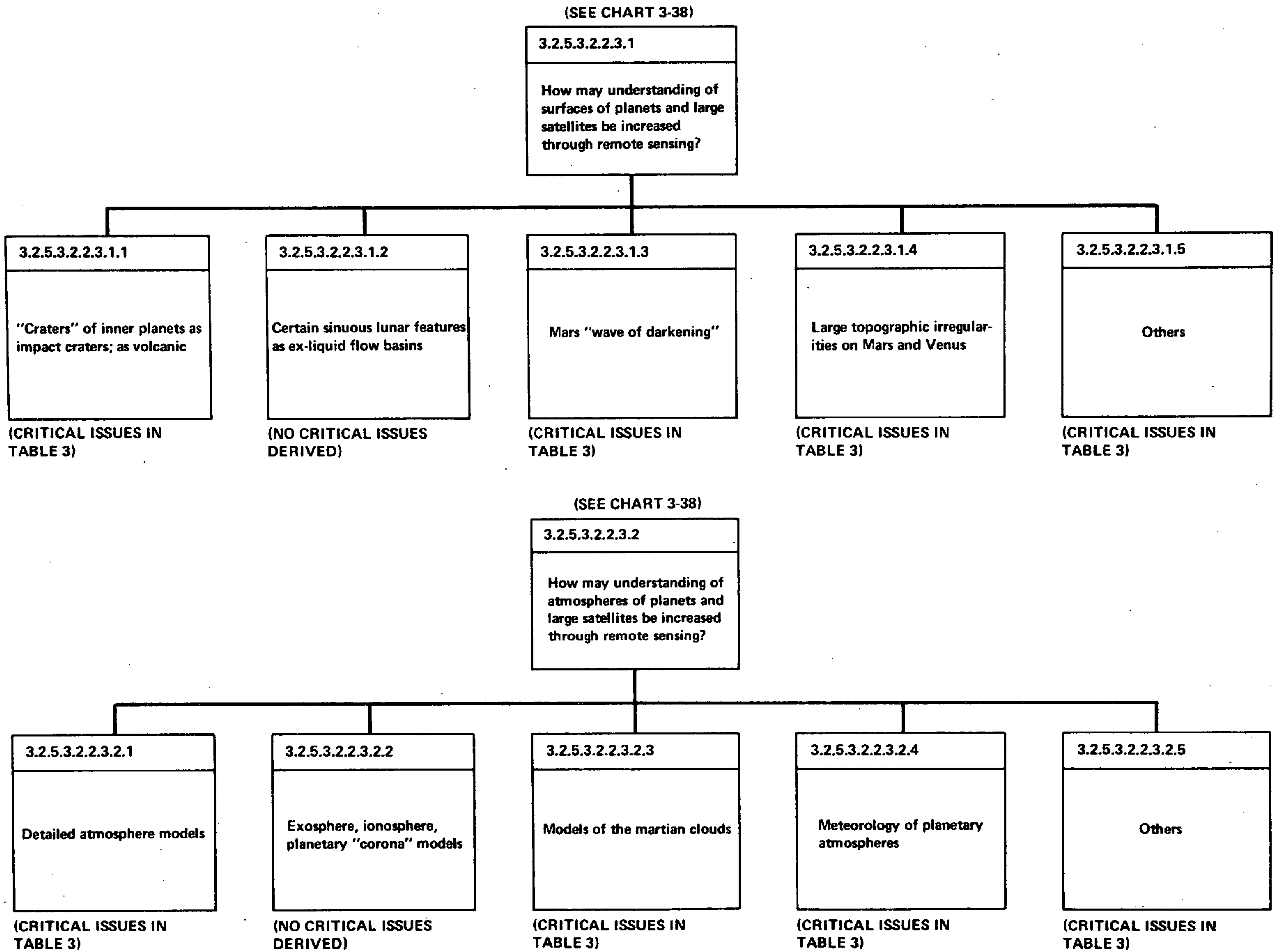


Chart 3-39. Space Astronomy – Understanding of Surfaces and Atmospheres of Planets and Large Satellites



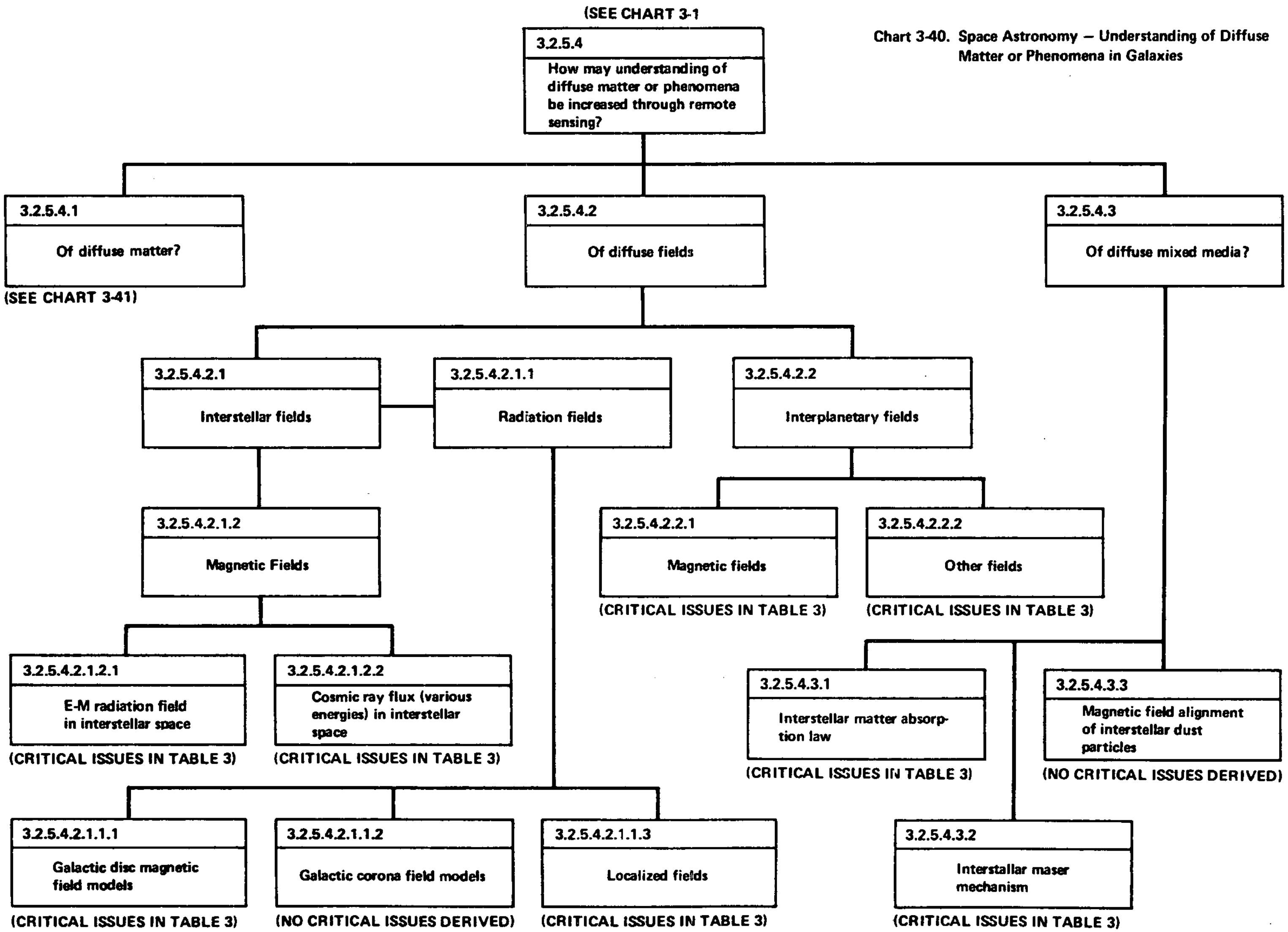
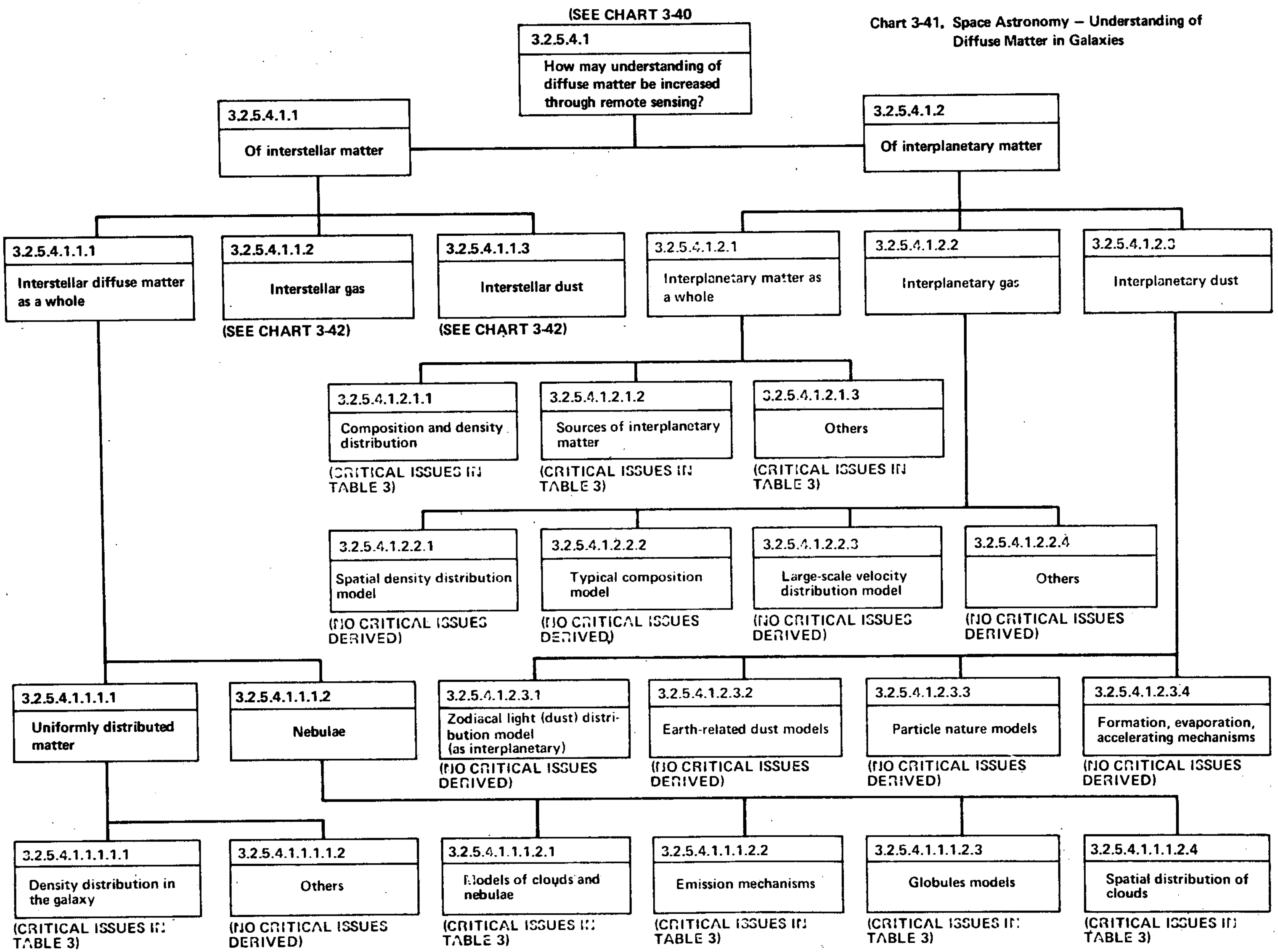


Chart 3-40. Space Astronomy – Understanding of Diffuse Matter or Phenomena in Galaxies

Chart 3-41. Space Astronomy – Understanding of Diffuse Matter in Galaxies



(SEE CHART 3-41)

- **3.2.5.4.1.1.2** How may understanding of interstellar gas be increased through remote sensing?
  - **3.2.5.4.1.1.2.1** Diffuse gas
    - **3.2.5.4.1.1.2.1.1** Typical composition models (atomic and molecular) — (CRITICAL ISSUES IN TABLE 3)
    - **3.2.5.4.1.1.2.1.2** Spatial density distribution — (NO CRITICAL ISSUES DERIVED)
    - **3.2.5.4.1.1.2.1.3** Heating and cooling mechanisms — (NO CRITICAL ISSUES DERIVED)
    - **3.2.5.4.1.1.2.1.4** Instability (cloud-forming) mechanisms — (NO CRITICAL ISSUES DERIVED)
    - **3.2.5.4.1.1.2.1.5** Large-scale velocity distribution — (NO CRITICAL ISSUES DERIVED)
  - **3.2.5.4.1.1.2.2** Gas clouds
    - **3.2.5.4.1.1.2.2.1** Ionized cloud zones — (CRITICAL ISSUES IN TABLE 3)
    - **3.2.5.4.1.1.2.2.2** High clouds as tracers of spiral structure — (NO CRITICAL ISSUES DERIVED)
    - **3.2.5.4.1.1.2.2.3** Heating and cooling mechanisms — (NO CRITICAL ISSUES DERIVED)
    - **3.2.5.4.1.1.2.2.4** HII Region evolution models — (NO CRITICAL ISSUES DERIVED)

(SEE CHART 3-41)

- **3.2.5.4.1.1.3** How may understanding of interstellar dust be increased through remote sensing?
  - **3.2.5.4.1.1.3.1** Particle nature models — (CRITICAL ISSUES IN TABLE 3)
  - **3.2.5.4.1.1.3.2** Spatial density distribution — (CRITICAL ISSUES IN TABLE 3)
  - **3.2.5.4.1.1.3.3** Formation and evaporation mechanisms — (NO CRITICAL ISSUES DERIVED)
  - **3.2.5.4.1.1.3.4** Others — (NO CRITICAL ISSUES DERIVED)

APPENDIX B

CRITICAL ISSUES

SPACE ASTRONOMY

Appendix B
INTRODUCTION

This appendix presents the series of 3,800 critical issues that comprise the principal result of the organized overview analysis of objectives for the six scientific and technical disciplines. The organized overview is described in Section 2 and graphically displayed in the charts contained in Appendix A.

In order to maintain the traceable indexing system carried through the charts shown in Appendix A, the numbers are repeated as major headings in Appendix B. Each critical issue thereby retains identity with the objectives and subobjectives from which it was derived.

The results of further analysis of the critical issues during the latter phases of the study are combined with the tabulation in this appendix by entering a code in the margin of the page, specifying the eventual disposition action. Table B-1 explains the code used for this assignment of critical issues.

In using Table B-1 to trace out the disposition, it is helpful to note that the principal consideration is whether or not the critical issue is addressed in at least one research cluster. In cases where this has occurred, the identifying serial number of the research cluster is used as the code. The alternative (2-letter) codes refer to categorical assignments of critical issues not included in the research cluster descriptions.

A summary of the disposition of the 3,800 critical issues in the six disciplines, according to the coding protocol of Table B-1, is presented in Table B-2.

Table B-1

CODE FOR DISPOSITION OF CRITICAL ISSUES

X-AB-YY	<u>Addressed in Research Cluster No. X-AB-XY</u> The first number (X) indicates the scientific or technical discipline, i.e., 1 - Manned Spaceflight Capability 2 - Space Biology 3 - Space Astronomy 4 - Space Physics 5 - Communications and Navigation 6 - Earth Observations The one- or two-letter code (AB) indicates the subdiscipline area, e.g., BR - Behavioral Research PP - Plasma Physics Laboratory A/F - Agriculture, Forest, and Range Resources The final number (YY) is a sequence number within the subdiscipline. Thus, 4-PP-3 is the third research cluster in the Plasma Physics Laboratory subdiscipline of the Space Physics discipline.
PS	<u>Eliminated by Preliminary Screening</u> Critical issue considered to be essentially peripheral to the scope of Earth orbital research. These issues were included in the report for the ideas that they might stimulate, but were not analyzed further.
NS	<u>Eliminated: Not an Earth Orbital Research Candidate</u> Critical issue judged to be more appropriate to research based elsewhere—terrestrial, sub-orbital, interplanetary trajectories, extraterrestrial bodies, etc.—after considering the advantages and disadvantages of various orbits and of the space environment.
UM	<u>Eliminated: Not a Manned Earth Orbital Research Candidate</u> Critical issue judged to be better suited to automated spacecraft than to manned Earth orbital research facilities, due either to the inability of man to contribute meaningfully to the research or to detrimental effects of man's presence.

Table B-1

CODE FOR DISPOSITION OF CRITICAL ISSUES (Continued)

OP	Eliminated: Covered in Ongoing Programs Critical issue whose research requirements are expected to be satisfied from the results of programs already in progress or firmly planned.
AC	Deferred, Due to Requirements for Advanced Concepts Critical issue for which no experimental approach is currently available, or for which advanced study or advanced ground-based developments should precede further programmatic analysis.
MS, SB, SA, SP, CN, or EO	Principally Concerned with Another Discipline Critical issue included in the organized overview analysis of a given discipline for the sake of completeness, but which is actually more germain to another discipline (indicated by symbol) and is analyzed further in that discipline.

Table B-2

DISPOSITION OF CRITICAL ISSUES

Code \ Discipline	Manned Spaceflight Capability	Space Biology	Space Astronomy	Space Physics	Communications and Navigation	Earth Observations	Totals
In Research Cluster Cluster (X-AB-YY)	785	361	154	154	90	439	1,983
Preliminary Screening (PS)	330	0	155	15	0	36	536
Not Earth Orbital (NS)	187	0	240	49	81	137	694
Not Manned Earth Orbital (UM)	0	0	21	23	0	35	79
Covered in Ongoing Programs (OP)	72	0	0	0	14	1	87
Requires Advanced Concepts (AC)	81	2	156	0	122	9	370
Referred to Another Discipline (MS, SB, etc.)	13	0	26	3	8	1	51
Totals	1,468	363	752	244	315	658	3,800

Table 3

SPACE ASTRONOMY CRITICAL ISSUES

3.1 KNOWLEDGE-INCREASE ISSUES

3.1.1 UNCLASSIFIED OBJECTS OR SOURCES

3.1.1.1 X-Ray Sources

3.1.1.1.1 Structure

.1 Diffuse Sources

.1.1 What are the angular sizes? UM

.1.2 How does the x-ray intensity vary across the sources? UM

.2 Discrete Sources

.2.1 What are the angular size and structure of discrete x-ray sources? 3-XR

3.1.1.1.2 Radiation Characteristics

.1 What are the spectral energy distributions of discrete x-ray sources? 3-XR

.1.1 How do discrete x-ray sources vary from source to source? 3-XR

.1.2 How do discrete x-ray sources vary as a function of time? 3-XR

.1.3 What are the Doppler shifts of the optical counterparts of discrete x-ray sources? 3-OW

.2 What polarizations if any, exist in discrete x-ray sources? 3-XR

3.1.1.1.3 Spatial Distribution and Miscellaneous

.1 What are the precise locations of the discrete x-ray sources? 3-XR

.2 What are the distances (from the sun) of the x-ray sources? PS

.3 What are the proper motions of the x-ray sources (optically identified)? NS

3.1.1.2 Gamma-Ray Sources

3.1.1.2.1 Structure of Diffuse Sources

.1 What is the angular distribution of the diffuse gamma-ray flux? UM

.2 What is the angular distribution of gamma radiation from diffuse sources, including separate background components? UM

.3 What, if any, temporal variations are there? UM

3.1.1.2.2 Radiation Characteristics

.1 What are the spectral flux distributions of the gamma ray sources? UM

.1.1 How do they vary from source to source? UM

.1.2 How do they vary as a function of time? UM

3.1.1.2.3 Spatial Distribution

.1 What is the angular distribution of the gamma-ray sources? UM

.2 What are the distances (from the sun) of the gamma ray sources? PS

3.1.1.2.4 Discrete Sources

.1 Do discrete gamma ray sources exist? UM

3.1.1.3 Unclassified Gravitational Radiators

.1 Where on the celestial sphere do gravitational radiators occur? SP

.2 What are the frequencies of the gravitational radiations? SP

.3 What are the detected energies of gravitational radiations? SP

3.1.1.4 Cosmic Ray Sources

.1 What fraction of detected cosmic rays of all energies are due to nonsolar sources? SP

.2 What are the energy spectra and apparent source locations of cosmis rays? SP

3.1.1.5 Peculiar Infrared Sources

.1 What is the angular distribution of peculiar IR sources? NS

.2 What are the optical counterparts of certain peculiar IR sources? 3-OS

.3 What are the distances of peculiar IR sources?

.4 How does the radiation of peculiar IR sources vary in time? 3-OS

.5 What is the polarization of peculiar IR sources? 3-OS

.6 What are the angular sizes and structures of peculiar IR sources? 3-OW

3.1.1.6 Other Unclassified Sources

.1 What presently unknown types of astronomical sources or objects exist? 3-LF,3-OS

3.1.2 UNIVERSE AS A WHOLE

.1 Does a significant amount of diffuse matter exist in the universe as a whole? NS

.2 What is the mean matter density (galaxies, clouds, diffuse matter combined) in the universe? NS

.3 What is the mean radiant energy density in the universe (EM and particle)? AC

.4 What is the true apparent-magnitude - spectral-redshift relation for remote galaxies? 3-OW

.5 What is the apparent-magnitude - angular-diameter relation? 3-OW

.6 What is the apparent-magnitude - number-density relation? 3-OW

3.1.3 ENSEMBLES OF GALAXIES

3.1.3.1 The System of Galaxy Clusters

.1 What is the highest order of clustering of galaxies? NS

.2 Are there 'classes' of galaxy clusters? NS

.3 Is there a variation of galaxy clustering with increasing spectral redshift? 3-OW

.4 What fraction of galaxies are involved in zero-order (noncluster), first order (cluster), second order (clusters of clusters), and etc., order of clustering? NS

3.1.3.2 Individual Galaxy Clusters

.1 What is the mass distribution (galaxies, clouds, etc.) in the local group and other clusters? NS

.2 What are the internal velocity distributions in various galaxy clusters? NS

3.1.4 INTERGALACTIC SPACE

3.1.4.1 Intergalactic Space as a Whole

3.1.4.2 Ensembles of Objects

.1 What is the spatial (number) density of intergalactic globular clusters? 3-OS

.2 How are intergalactic globular clusters spatially related to nearby galaxies? NS

3.1.4.3 Discrete Objects

3.1.4.3.1 Quasi-Stellar Radio Sources (Quasars)

3.1.4.3.1.1 Structure

.1 What are the angular sizes and structures of quasars? 3-OW

3.1.4.3.1.2 Radiation Characteristics

.1 What are the spectral flux distributions and luminosities of the quasars? 3-LF,3-OW

.1.1 How do the quasars vary with time? 3-LF,3-OW

.1.2 How do the quasars vary from source to source? 3-LF,3-OW

.2 What are the polarizations of quasar radiation? Are there variations with wavelength and time? 3-LF,3-OW

3.1.4.3.1.3 Spatial Distribution, Motion, and Miscellaneous

.1 What is the angular distribution of the quasars? NS

.2 What are the apparent proximities of quasars to other normal, peculiar, etc., galaxies? NS

.3 What are the distances (from the sun) of the quasars? NS

.4 What, if any, are the proper motions of the quasars? NS

3.1.4.3.2 Other Discrete Objects

.1 Do stars occur in intergalactic space? With what spatial density? AC

3.1.4.4 <u>Diffuse Matter and Fields</u>

3.1.4.4.1 Diffuse Intergalactic Fields

.1	What is the spectral distribution of EM radiation from the 'cosmic' background?	AC
.2	What is the angular distribution of EM radiation from the 'cosmic' background?	AC
.3	Is there an intergalactic magnetic field?	3-OW

3.1.4.4.2 Diffuse Intergalactic Matter

.1	Is there evidence for anisotropy or angular variations in the radiation from intergalactic space?	3-XR, 3-LF
.2	What is the typical temperature of intergalactic diffuse matter?	3-XR,3-LF
.3	What is the typical density of intergalactic diffuse matter?	3-XR,3-LF
.4	What is the composition of intergalactic diffuse matter?	AC
.5	Is there a cosmic ray flux apparently coming from intergalactic space?	SP

3.1.4.4.3 Diffuse Mixed Matter and Fields

3.1.5 GALAXIES

3.1.5.1 <u>Galaxies as a Whole</u>

3.1.5.1.1 The Galaxy

.1	What is the total mass of the Galaxy?	NS
.2	What fraction of the total mass of the Galaxy is in stars? In gas? In dust? In any other objects (e.g., dead stars)?	NS
.3	What is the smoothed three-dimensional galactic mass distribution?	NS

.4 What is the true spiral arm structure in the galactic disc, as traced by stars, nebulae, and diffuse matter? NS

.5 What is the structure of the galactic nucleus? NS

.6 What is the stellar population breakdown by spectral class? NS

.7 What fraction of stars, by type, occur in clusters? In associations? In moving groups? Singly? NS

.8 What is the galactic rotation speed as a function of distance from the axis and from the plane? NS

.9 What is the structure of the galactic 'hat brim'? 3-LF

.10 Are there not-as-yet classified or unknown large-scale structures in the Galaxy? 3-LF

.11 What are the space velocities of young stars relative to diffuse matter? NS

.12 What is the structure of the galactic corona? 3-LF

.13 What is the composition of the galactic corona? AC

.14 How is the composition of the galactic corona related to Population II and globular clusters? NS

.15 How is the structure of the galactic corona related to Population II and globular cluster halos? NS

.16 What is the stellar spatial distribution in the galaxy by spectral class of stars? NS

3.1.5.1.2 Other Galaxies

.1 What are the total masses and characteristic dimensions of galaxies as a function of type and luminosity? NS

.2 What are the total masses of stars in galaxies as a function of type and luminosity? NS

.3 What are the total masses of diffuse matter in galaxies as a function of type and luminosity? NS

.4 What stellar populations are found in galaxies as a function of types and luminosity? 3-OW

.5 What is the detailed stellar content of certain galaxies of various types? PS

.6 What is the spectral flux distribution at diverse points in galaxies of various types? 3-OW

.7 What are the rotation velocities at various points in certain galaxies? 3-OW

.8 What are improved distances of galaxies beyond 10 megaparsecs (mpc)? 3-OS

3.1.5.2 Ensembles of Objects

3.1.5.2.1 Stellar Ensembles

3.1.5.2.1.1 Globular Clusters

.1 What is the structure of globular clusters? 3-OS

.2 What is the chemical composition of globular cluster stars? 3-OS

3.1.5.2.1.2 Galactic Clusters

.1 What are the characteristics in the H-R diagram of the zero-age main sequence of galactic clusters? NS

3.1.5.2.1.3 Stellar Associations

.1 What presently unknown OB and T associations exist? NS

3.1.5.2.1.4 Multiple Stars

.1 What are the orbital elements of a large sample of binary systems, and the indicated masses and radii? 3-OW

3.1.5.2.2 Solar Systems

3.1.5.2.2.1 The Solar System

3.1.5.2.2.1.1 The Solar System as a Whole

.1 How is the orbit of Pluto changing, especially relative to Neptune? NS

.2 Is there a correlation between solar activity and dynamic properties of the inner planet orbits? NS

.3 For times substantially longer than presently considered, how is the Earth's orbit varying? NS

.4 How is the moon's orbit varying as a function of time? NS

.5 How do the orbits of the Jupiter-influenced comets and asteroids compare? NS

.6 How do the high-eccentricity comet and asteroid orbits compare? NS

3.1.5.2.2.1.2 Comet System

.1 What is the observable total mass of the comet system to M limiting magnitude? AC

3.1.5.2.2.1.3 Other Solar Subsystems

.1 Are there significant changes in Saturn's ring structure? NS

.2 Does Jupiter possess a small particle ring (as Saturn does? NS

.3 Does Earth possess Lagrangian point satellites? AC

.4 How are the orbits of the Martian, Jupiter V, and other 'close' satellites varying? NS

3.1.5.2.2.2 Solar Systems as a Whole

.1 How do the orbits and masses of 'dark' companions of nearby stars compare with solar system planets? NS

.2 What is the number of dwarf stars (late types) with dark companions per cubic pc or as a fraction of same type stars ? NS

3.1.5.2.2.3 Other Solar Systems

.1 Which nearby stars exhibit periodic proper motion variations not attributable to visible companions ? PS

.2 What are the indicated orbits and masses of 'dark' companions ? NS

.3 Do any nearby dwarf stars exhibit periodic brightness microfluctuations possibly indicating transits by "dark" companions ? 3-OP

3.1.5.3 Discrete Objects

3.1.5.3.1 Stars

3.1.5.3.1.1 Stars as a Whole

.1 What are the masses of stars as a function of spectral type ? NS

.2 What are the compositions of stars as a function of spectral type ? NS

.3 What are the angular momenta of stars as a function of spectral type ? NS

.4 How does the probability of stars ejecting material depend on evolution ? NS

.5 What are the properties of suspected prefusion stars ? 3-OW

3.1.5.3.1.2 Prefusion Stars

.1 What is the space distribution of T Tauri and related stars? NS

.2 What is the space motion of T Tauri and related stars ? NS

.3 What is the size distribution of T Tauri and related stars ? NS

.4 What are the masses of T Tauri and related stars ? NS

.5 What are the exterior rotation velocities of T Tauri and related stars? NS

.6 What are the magnetic fields of T Tauri and related stars? NS

.7 What other stars are prefusion stars? NS

3.1.5.3.1.3 Fusion Stars

3.1.5.3.1.3.1 Fusion Stars as a Whole

3.1.5.3.1.3.1.1 The Sun

.1 What is the mass of the Sun to better accuracy than presently known? NS

3.1.5.3.1.3.1.2 Other Stars

.1 What are the masses of other stars? NS

3.1.5.3.1.3.2 Fusion Star Exteriors

3.1.5.3.1.3.2.1 Exterior of the Sun

3.1.5.3.1.3.2.1.1 Exterior as a Whole

3.1.5.3.1.3.2.1.1.1 Propagation Phenomena

.1 What paths do flare- and surge-generated particles take in traversing the solar atmosphere? 3-LF

.2 What are their attrition rates as functions of particle types and energies? AC

.3 Are there discernible radially traveling waves? AC

.4 Which are sound waves? Alfven waves? Shock waves? AC

.5 What are the three-dimensional trajectories of puffs? AC

3.1.5.3.1.3.2.1.1.2 Structure

3.1.5.3.1.3.2.1.1.2.1 Structure as a Whole

3.1.5.3.1.3.2.1.1.2.1.1 Fields

.1 What is the fine structure of the general magnetic field as a function of time? AC

.2 What are the transverse components of magnetic loops, etc? AC

3.1.5.3.1.3.2.1.1.2.1.2 Matter

.1 Can ray structures in the corona be traced down to the photosphere? UM

3.1.5.3.1.3.2.1.1.2.1.3 Currents

.1 Is there a flow of matter from the polar surface areas through to atmosphere to the vicinity of the lower chromosphere in the equatorial regions? AC

.2 What are the overall convective and turbulence currents as a function of height and latitude? AC

3.1.5.3.1.3.2.1.1.2.2 Profiles of Intensive Quantities

3.1.5.3.1.3.2.1.1.2.2.1 Temperature

.1 What is the overall gross temperature distribution with height as a function of time? Latitude? Longitude? AC

.2 What is the plot of the temperature discontinuity at the spicule-corona interface? AC

3.1.5.3.1.3.2.1.1.2.2.2 Density

.1 What is the overall gross density distribution with height as a function of time? Latitude? Longitude? AC

3.1.5.3.1.3.2.1.1.2.2.3 Composition

.1 What is the abundance of helium in the Sun? AC

.2 What is the percent distribution of calcium as a function of time and position in the Sun? AC

3.1.5.3.1.3.2.1.1.2.2.4 Radiation

.1 The gross structure of the radiation from the photosphere-chromosphere interface is evident; what is the fine structure and its relationship to the spectrum? AC

3.1.5.3.1.3.2.1.1.2.2.5 Other

.1 What is the general rotation rate as a function of height and latitude? (And longitude?) AC

3.1.5.3.1.3.2.1.1.3 Prominences

.1 What is the three-dimensional magnetic field structure of prominences? AC

3.1.5.3.1.3.2.1.2 Photosphere

3.1.5.3.1.3.2.1.2.1 Photosphere as a Whole

3.1.5.3.1.3.2.1.2.1.1 Propagation Phenomena

.1 Are there gravity waves in the photosphere? AC

.2 Are there Alfven waves in the areas of intense magnetic fields? AC

.3 Are there shock waves? AC

3.1.5.3.1.3.2.1.2.1.2 Structure

3.1.5.3.1.3.2.1.2.1.2.1 Structure as a Whole

3.1.5.3.1.3.2.1.2.1.2.1.1 Fields

.1 What is the general magnetic field of the photosphere? 3-SO

.2 How does the photosphere vary with time? 3-SO

3.1.5.3.1.3.2.1.2.1.2.1.2 Matter

.1 What appearance do equal-density surfaces have? AC

.2 What appearance do equal-temperature surfaces have? AC

3.1.5.3.1.3.2.1.2.1.2.1.3 Currents

.1 Are there any observable flow patterns discernible down to <u>x</u> km/sec? AC

3.1.5.3.1.3.2.1.2.1.2.2 Profiles of Intensive Quantities

3.1.5.3.1.3.2.1.2.1.2.2.1 Temperature

.1 How do temperature profiles at various latitudes compare? AC

.2 As a function of time? AC

3.1.5.3.1.3.2.1.2.1.2.2.2 Density

3.1.5.3.1.3.2.1.2.1.2.2.3 Composition

.1 What is the atomic and molecular composition of the photosphere as a function of height? 3-SO

3.1.5.3.1.3.2.1.2.1.2.2.4 Radiation

.1 What is the relation between height and optical depth as a function of wavelength? AC

.2 As a function of time? AC

3.1.5.3.1.3.2.1.2.1.2.2.5 Other

3.1.5.3.1.3.2.1.2.2 Spots

3.1.5.3.1.3.2.1.2.2.1 Structure

.1 How does temperature vary radially and heightwise in sun spots? 3-SO

.2 How does the magnetic field vary radially and heightwise in sun spots? 3-SO

.3 Are there photospheric lateral currents exerting pressure on sunspots? 3-SO

3.1.5.3.1.3.2.1.2.2.2 Statistical and Temporal Properties

.1 What are the detailed proper motions of spots? NS

.2 What are the sun spot granulation lifetimes? 3-SO

3.1.5.3.1.3.2.1.2.3 Granulation

.1 What do the interstitial regions of the photosphere granulation look like at resolutions better than 0.5 arc sec? 3-SO

.2 Do photosphere granule lifetimes vary with the solar cycle? 3-SO

.3 Does chemical composition vary from photosphere granule centers to interstitial region centers? 3-SO

3.1.5.3.1.3.2.1.3 Chromosphere

3.1.5.3.1.3.2.1.3.1 Chromosphere as a Whole

3.1.5.3.1.3.2.1.3.1.1 Propagation Phenomena

.1 Are there precursor waves traveling from solar flare centers to later-flaring elements of major flares? 3-LF

3.1.5.3.1.3.2.1.3.1.2 Structure

3.1.5.3.1.3.2.1.3.1.2.1 Structure as a Whole

3.1.5.3.1.3.2.1.3.1.2.1.1 Fields

.1 What are the transverse magnetic components of the fields found in filament and flaring regions? AC

3.1.5.3.1.3.2.1.3.1.2.1.2 Matter

.1 Is there a synoptic change in upper chromospheric density in the polar areas with sunspot cycle? AC

3.1.5.3.1.3.2.1.3.1.2.1.3 Currents

.1 Is there a wind flowing in the chromosphere that blows the prominences poleward but shifts or changes so that they collect at approximately ±70 deg latitude: AC

.2 What are the convective and turbulence currents as a function of height and latitude? AC

3.1.5.3.1.3.2.1.3.1.2.2 Profiles of Intensive Quantities

3.1.5.3.1.3.2.1.3.1.2.2.1 Temperature

.1 How does the vertical chromospheric temperature profile vary as a function of latitude and time? 3-SO

.2 Are there anomalies or fine structure in the vertical chromospheric temperature profile. 3-SO

3.1.5.3.1.3.2.1.3.1.2.2.2 Density

.1 How does the density profile of the chromosphere vary as a function of latitude and time? 3-SO

.2 Are there anomalies or fine structure in the density profile of the chromosphere? 3-SO

3.1.5.3.1.3.2.1.3.1.2.2.3 Composition

.1 How does the composition of the chromosphere vary as a function of height, latitude, and time? 3-SO

.2 Are there anomalies? PS

3.1.5.3.1.3.2.1.3.1.2.2.4 Radiation

.1 What is the synoptic variation of the chromospheric spectrum throughout the UV and XUV? 3-SO

3.1.5.3.1.3.2.1.3.1.2.2.5 Other

3.1.5.3.1.3.2.1.3.2 Spicules

.1 Is there a magnetic field within the spicules? 3-SO

.2 What is the structure of any magnetic field in the spicules? 3-SO

3.1.5.3.1.3.2.1.3.3 Plages

.1 What is the temperature of plages? NS

.2 How strong must magnetic fields be for their formation and maintenance? NS

.3 What is the temperature of calcium plages? NS

.4 How strong must magnetic fields be for calcium plage formation and maintenance? PS

3.1.5.3.1.3.2.1.3.4 Flares

.1 What is the three-dimensional magnetic field geometry in a flare area, before, during, and after a solar flare, to <5 arc sec resolution? 3-SO

.2 What are the upper and lower altitudes of flares? AC

.3 What is the UV emission line spectrum of solar flares? 3-SO

.4 What is the fine structure of solar flare fibrils? 3-SO

3.1.5.3.1.3.2.1.3.5 Supergranulation

.1 What are the velocities of the currents connected with supergranulation cells? PS

3.1.5.3.1.3.2.1.4 Corona

3.1.5.3.1.3.2.1.4.1 Corona as a Whole

3.1.5.3.1.3.2.1.4.1.1 Propagation Phenomena

.1 What are the three-dimensional trajectories of the sources of Type IV radio bursts in the solar corona? 3-LF

.2 Is the corona subject to continuous 'noise' of shock waves emanating from below or within its lower layers? AC

.3 At what height do they finally dissipate? AC

.4 What energy (as a function of height) is transferred to the corona as heat? AC

3.1.5.3.1.3.2.1.4.1.2 Structure

3.1.5.3.1.3.2.1.4.1.2.1 Strcuture as a Whole

3.1.5.3.1.3.2.1.4.1.2.1.1 Fields

.1 What is the overall three-dimensional magnetic field in the environment of a helmet? AC

3.1.5.3.1.3.2.1.4.1.2.1.2 Matter

.1 Are there well-defined areas of rarification similar to those of increased density? AC

3.1.5.3.1.3.2.1.4.1.2.1.3 Currents

3.1.5.3.1.3.2.1.4.1.2.1.3.1 Solar Wind

.1 Does the solar wind have its origin in heliographically restricted regions, rather than being a (modified) general coronal expansion? 3-LF

.2 Does the solar wind halt within the solar system? NS

.3 Is the solar wind circularly asymmetric with respect to heliocentric latitude? NS

.4 Does the composition vary? NS

.5 What are the temporal variations of the above? NS

3.1.5.3.1.3.2.1.4.1.2.1.3.2 Others

3.1.5.3.1.3.2.1.4.1.2.2 Profiles of Intensive Quantities

3.1.5.3.1.3.2.1.4.1.2.2.1 Temperature

.1 How do average temperature profiles within fans vary? AC

.2 How do average temperature profiles within rays vary? AC

.3 How do average temperature profiles outside fans and rays vary? AC

3.1.5.3.1.3.2.1.4.1.2.2.2 Density

.1 How do average density profiles within fans vary? AC

.2 How do average density profiles within rays vary? AC

.3 How do average density profiles outside fans and rays vary? AC

3.1.5.3.1.3.2.1.4.1.2.2.3 Composition

.1 What is the composition as a function of height and latitude? AC

.2 Are there any anomalies? AC

3.1.5.3.1.3.2.1.4.1.2.2.4 Radiation

.1 What is the correlation with height of the optical depths for the spectral lines in the XUV? AC

3.1.5.3.1.3.2.1.4.1.2.2.5 Other

.1 What are the temporal variations of the above, short and long term? AC

3.1.5.3.1.3.2.1.4.2 Polar Rays

.1 What is the lifetime of individual rays? AC

.2 What are the magnetic field strengths in the rays and in the interstitial spaces? AC

.3 What is the material velocity in the rays? AC

.4 What is the temperature variation in the rays with height? AC

3.1.5.3.1.3.2.1.4.3 Helmets and Fans

.1 Are fans areas of enhanced outward streaming of matter? AC

.2 Are there always prominences at the bases of helmets? AC

.3 What is the three-dimensional magnetic structure at the bases of helmets? AC

3.1.5.3.1.3.2.2 Other Stars

3.1.5.3.1.3.2.2.1 Exteriors as a Whole

.1 What is the spectral distribution of radiation from normal stars of all types? As a function of time? AC

.2 What is the radiation spectral distribution (in more detail than above) from typical, and certain specially interesting normal stars of various types? AC

.3 What are the observable apparent Doppler shifts and broadenings in certain lines for normal stars? UM

.4 Is there Zeeman splitting (and to what degree) in certain lines of normal stars? NS

3.1.5.3.1.3.2.2.2 Photospheres

.1 What is the spectral flux distribution of stellar radiation in the ultraviolet and infrared wavelength ranges? PS

3.1.5.3.1.3.2.2.3 Chromospheres and Coronas

.1 Which types of stars have corona and chromospheric type emissions? AC

3.1.5.3.1.3.2.2.4 Planetary Nebulae, and Nova and Supernova Ejecta

.1 What is the three-dimensional structure of a large sample of planetary nebulae, including inhomogeneities? 3-OW

.2 How is the structure related to the emitting regions? PS

.3 What is the typical composition of planetary nebulae? AC

.4 What are the mass, size, and composition of known nova and supernova ejecta? AC

.5 What nebulae not presently so identified are nova or supernova ejecta? NS

3.1.5.3.1.3.3 Fusion Star Interiors

3.1.5.3.1.3.3.1 The Sun

.1 What is the solar neutrino flux? NS

3.1.5.3.1.4 Postfusion Stars

3.1.5.3.1.4.1 Pulsars

3.1.5.3.1.4.1.1 Spatial Distribution

.1 What is the angular distribution of pulsars? NS

.2 What are the optical counterparts of pulsars? 3-OS

.3 What are the apparent proximities of pulsars to discrete x-ray sources? 3-XR,3-OS

.4 What are the distances (from the Sun) of pulsars? NS

3.1.5.3.1.4.1.2 Radiation Characteristics

.1 What are the pulse periods and period changes of pulsars? 3-XR,3-OS

.2 What are the spectral flux distributions of the pulsars as a function of time in pulses and between pulses? 3-XR,3-OS,3-LF

3.1.5.3.1.4.1.3 Structure

.1 What are the angular sizes and structures of pulsars? 3-OW

3.1.5.3.1.4.2 White Dwarfs

.1 What are the masses and sizes of white dwarfs? NS

.2 What is the spectral distribution of radiation of white dwarfs? 3-OW

3.1.5.3.1.4.3 Planetary Nebula Central Stars

.1 What are the masses, sizes, and spectral distributions of planetary nebula stars? 3-OW

3.1.5.3.1.4.4 Others

.1 What are the masses, sizes, and spectral distributions of postfusion stars other than pulsars, white dwarfs, and planetary nebula stars? 3-OW

3.1.5.3.2 Large Bodies

3.1.5.3.2.1 Large Bodies as a Whole

.1 How do large body densities vary as a function of mass? NS

.2 How do large body compositions vary as a function of mass? NS

3.1.5.3.2.2 Planets and Large Satellites

3.1.5.3.2.2.1 Planets and Large Satellites as a Whole

.1 What are the sizes and masses of the planets and large satellites to higher accurcies? 3-OW

.2 What is the oblateness of the planets and large satellites? 3-OW

.3 What relation exists between topographic features and planet sizes and masses: NS

.3.1 For Mars, Mercury, and the moon (to comparable resolution)? NS

.3.2 For Io, Europa, Ganymede, Callisto, Titan, and Triton? NS

.3.3 For the giant planets? NS

.4 Do any planets other than Earth and Jupiter have general magnetic fields? NS

.5 What are improved sizes and shapes of Uranus, Neptune, and Pluto? 3-OW

3.1.5.3.2.2.2 Interiors

.1 What is the internal structure of the terrestrial and giant planets? NS

3.1.5.3.2.2.3 Exteriors

3.1.5.3.2.2.3.1 Surfaces

.1 Are volcanic activity and outgassing presently occurring on the Moon's surface? Where? NS

.2 Are volcanic activity and outgassing presently occurring on Mars' surface? Where? 3-OB

.3 Can extant meteoric bombardment of the Moon be observed? NS

.4 What is the meteoric flux? NS

.5 Can extant meteoric bombardment of the Martian surface be detected? NS

.6 What is the meteoric flux? NS

.7 What long-term surface feature changes occur on Mars at 10- to 50-mi spatial resolution? 3-OP

.8 What is the coarse topography of Venus? NS

.9 What is the appearance of Mercury at 50-mi spatial resolution? 3-OB

.10 What is the appearance of the large satellites of Jupiter and Saturn with a few hundred miles spatial resolution? 3-OW

.11 What is the surface material of the high-albedo satellites? AC

.12 Do the Martian polar caps contain CO_2, H_2O, or neither? AC

.13 Are there mountain chains on Mars or Mercury? 3-OB

.14 What is the physical composition of the Martian surface material? NS

.15 What is the chemical composition of the Martian surface material? NS

.16 What is the typical chemical composition of the Venusian surface material? NS

.17 What is the typical physical composition of the Venusian surface material? NS

3.1.5.3.2.2.3.2 Atmospheres

.1 What is the meteorology of Mars with 10- to 50-mi spatial resolution? 3-OB

.2 What are the wind velocities? NS

.3 Is our current knowledge of the gaseous composition of Venus' atmosphere correct? NS

.4 Is our current knowledge of the height variations of density temperature of Venus' atmosphere correct? NS

.5 Are oxygen and water vapor present in the atmosphere of Venus? ND

.6 What is the particulate component composition of Venus' atmosphere? ND

.7 What are the density and composition of Mercury's atmosphere (if any)? 3-OB

3.1.5.3.3 Small Bodies

3.1.5.3.3.1 Small Bodies as a Whole

.1 What is the range of size and mass of small planetary satellites, asteroids, comet nuclei, and meteoroids considered together? NS

.2 What are the surface structures and compositions of small bodies, and how do these compare? NS

3.1.5.3.3.2 Comets

.1 What are the size, structure, and mass of comet nuclei, and how do these vary during perihelion passage? 3-OW

.2 What are the three-dimensional structure and orientation of comet tails as a function of time near perihelion passages? NS

.3 What is the typical composition of comet nuclei? AC

.4 What is the typical composition of comet comas and tails? NS

.5 What is the total mass of comets, including invisible matter? AC

3.1.5.3.3.3 Subplanetary Bodies

.1 What are the mass, size, and shape of Mars' satellites? NS

.2 Do microasteroids exist, and if so, what are their masses, and sizes? 3-OS

.3 What are the mass and size of the largest meteoroids? NS

.4 What is the surface material composition of Iapetus (Saturn VIII) and some other selected small planetary satellites? PS

.5 What is the surface material composition of typical large asteroids and typical near-earth-passing asteroids? PS

.6 What is the composition of the material forming Saturn's ring? AC

.7 Do any of the planets possess presently unknown satellites? 3-OS

3.1.5.3.3.4 Others

.1 Are there presently unknown types of small bodies in the solar system? 3-OS

.2 Are there real 'cloud' satellites at the libration points of the Earth-moon system? What are their sizes, masses, and composition? PS

3.1.5.4 <u>Diffuse Matter and Fields</u>

3.1.5.4.1 Diffuse Matter

3.1.5.4.1.1 Interstellar Diffuse Matter

3.1.5.4.1.1.1 Interstellar Diffuse Matter as a Whole

3.1.5.4.1.1.1.1 Uniformly Distributed Matter

.1 What is the typical gas/dust density ratio in the Galaxy and other galaxies? NS

.2 What are the systematic and turbulent velocities in the interstellar matter in the Galaxy and other galaxies? 3-OW

3.1.5.4.1.1.1.2 Nebulae

.1 What are the mass, size, and structure of bright nebulae? 3-OW,3-LF

.2 What are the temperature and composition of bright nebulae? 3-OW,3-LF

.3 How are dark nebulae distributed in space? NS

.4 What are the mass, size, and structure of dark nebulae and clouds? 3-OW

.5 What are the temperature and composition of dark nebulae and clouds? AC

3.1.5.4.1.1.2 Interstellar Gas

3.1.5.4.1.1.2.1 Diffuse Gas

.1 What is the smoothed spatial density distribution of interstellar gas in the Galaxy and in other galaxies? 3-LF

.2 What is the gas velocity in inner regions of the Galaxy? NS

3.1.5.4.1.1.2.2 Gas Clouds

.1 What are improved electron temperatures and densities in HII regions? 3-LF

.2 What are the temperatures of HII regions? 3-LF

.3 Do ionization zones of HeII and other atoms exist? AC

.4 What are the apparent sizes of HII regions in galaxies in the 10- to 100-mpc distance range? 3-OS

.5 What are the gas velocities in nebulae of all types? AC

.6 What are characteristic sizes and masses of large interstellar gas clouds in the Galaxy? 3-LF

.7 What are the temperatures of large interstellar clouds in the Galaxy? 3-LF

3.1.5.4.1.1.3 Interstellar Dust

.1 What is the typical physical nature (size, shape, electromagnetic properties) of interstellar dust in the Galaxy? AC

.2 Are there significant spatial variations in the dust particle types? AN

.3 How is dust distributed in other galaxies? NS

3.1.5.4.1.2 Interplanetary diffuse Matter

3.1.5.4.1.2.1 Interplanetary Matter as a Whole

.1 What is the smoothed spatial density distribution of dust and gas in the solar system? AC

.2 What is the structure of the interplanetary plasma? 3-LF

.3 What is the macroscopic velocity distribution in the interstellar medium? NS

3.1.5.4.1.2.2 Interplanetary Gas

.1 What is the chemical composition of interplanetary gas? NS

3.1.5.4.1.2.3 Interplanetary Dust

.1 What is the physical nature (size, shape, electromagnetic properties) of the interplanetary dust? AC

3.1.5.4.2 Diffuse Fields

3.1.5.4.2.1 Interstellar fields

3.1.5.4.2.1.1 Magnetic Fields

.1 What is the typical magnetic field strength in the interstellar medium, and are there large deviations from this average? 3-LF

.2 How is the interstellar field oriented? AC

3.1.5.4.2.1.2 Radiation Fields

.1 What is the cosmic ray flux in interstellar space? SP

3.1.5.4.2.2 Interplanetary Fields

3.1.5.4.2.2.1 Magnetic Fields

.1 What are the smoothed interplanetary magnetic field strength and structure at various heliocentric distances? AC

.2 How does the magnetic field vary in the vicinity of planets? NS

.3 How does the field vary with time at various places? NS

3.1.5.4.2.3 Diffuse Mixed Matter and Fields

.1 What are the sources of interstellar masers? NS

.2 What is the interstellar matter absorption per unit distance at all wavelengths in various directions in space? AC

3.2 THEORY-GENERATED ISSUES

3.2.1 UNCLASSIFIED OBJECTS OR SOURCES

3.2.1.1 X-Ray Sources

3.2.1.1.1 As a Whole

3.2.1.1.1.1 Wolf-Rayet Stars as Sources

.1 What is the relationship of x-ray sources with Wolf-Rayet stars? NS

3.2.1.1.1.2 Neutron Stars as Sources

.1 What is the relationship of x-ray sources with neutron stars? NS

3.2.1.1.1.3 Shells, Ejecta as Sources

.1 What are the apparent proximities of x-ray sources to known supernova ejecta, or shells? 3-OS

3.2.1.1.1.4 Galaxies as Sources

.1 Are x-ray sources co-located with some galaxies? 3-OS

3.2.1.1.1.5 Nebulae as Sources

.1 Are X-ray sources co-located with nebulae? 3-OS

3.2.1.1.2 Radiation Mechanisms

3.2.1.1.2.1 Bremstrahlung Emission

.1 What is the polarization of the various x-ray sources? PS

.2 What is the spectral distribution of the radiation energy? PS

3.2.1.1.2.2 Synchrotron Emission

.1 What is the polarization of the various x-ray sources' emission? PS

.2 What is the spectral distribution of the radiation? PS

3.2.1.1.2.3 Line Emission

.1 What is the fine spectral distribution of the line-emission radiation of x-ray sources? 3-XR

3.2.1.1.3 Miscellaneous

3.2.1.1.3.1 Starlike Distribution of Discrete Sources

.1 What is the spatial distribution of the discrete x-ray sources? 3-XR

3.2.1.1.3.2 Diffuse Sources in the Galaxy

.1 Are there diffuse x-ray sources in the Galaxy? UM

3.2.1.1.3.3 Intergalactic Gas as Source of Diffuse Background

.1 What is the angular distribution of the diffuse background? PS

.2 Is the x-ray background attributable to intergalactic gas only? UM

3.2.1.1.3.4 Superposition of Galaxies as a Source of Diffuse Background

.1 Does this background show any discreteness? UM

3.2.1.2 Gamma Ray Sources

3.2.1.2.1 Gamma Ray Sources as a Whole

3.2.1.2.1.1 Stars as Discrete Sources

.1 Are stars co-located with any discrete gamma ray sources? 3-OS

3.2.1.2.1.2 Galaxies as Discrete Sources

.1 Are there galaxies co-located with some sources? AC

3.2.1.2.1.3 Nebulae as Diffuse Sources

.1 Are gamma ray sources co-located with nebulae? AC

3.2.1.2.1.4 Others

3.2.1.2.2 Radiation Mechanisms

3.2.1.2.2.1 Bremstrahlung Emission

.1 What is the spectral distribution of the radiation from gamma ray sources? PS

3.2.1.2.2.2 Synchrotron Emission

.1 What is the spectral distribution of the radiation from gamma ray sources? PS

3.2.1.2.2.3 Nuclear Transitions (Line Emission)

.1 Are there emission lines in the spectra of gamma ray sources? AC

3.2.1.2.3 Miscellaneous

3.2.1.2.3.1 Galactic Gas as a Source of Diffuse Background

.1 Is the angular distribution of diffuse gamma radiation correlated with known galactic structure? UM

3.2.1.2.3.2 Intergalactic Gas as a Source of Diffuse Background

.1 Is there an isotropic component of the background? UM

3.2.1.2.3.3 Diffuse Background as Composite of Galactic and Extragalactic Sources

.1 Is there more than one distinct component of the diffuse background? PS

.2 What is the angular distribution of the diffuse flux? PS

.3 Is there any evidence for discreteness? UM

3.2.1.3 Gravitational Radiators

3.2.1.3.1 Close Encounters as Sources

.1 What is the rate at which gravitational radiation "pulses" are detected at Earth? SP

.2 What are the detected pulse energies? SP

.3 Do extremely dense "stars" occur in binary systems (e.g., are there binary pulsars)? NS

3.2.1.3.2 Other Sources

.1 Is there a background of "continuous" gravitational radiation? SP

.2 What directionalities do the detected gravitational pulses show? SP

3.2.1.4 Cosmic Ray Sources

3.2.1.4.1 Supernovae as Sources

.1	What is the composition of galactic cosmic rays?	SP
.2	What are the energy spectra of the various particle species?	SP
.3	What are the velocities of cosmic ray particles of various energies?	SP
.4	What are the distances, to somewhat better accuracy than presently known, of recognized ex-supernovae in the Galaxy?	NS
.5	What directionalities do detected cosmic rays exhibit, allowing for geomagnetic and solar magnetic field deflections?	SP

3.2.1.4.2 Normal Stars as Sources

.1	What is the composition of galactic cosmic rays?	SP
.2	What are the energy spectra of the various particle species?	SP
.3	What are the velocities of cosmic ray particles of various energies?	SP
.4	What are the distances of the known flare stars?	NS
.5	What are the flare luminosities in flare stars?	3-OP

3.2.1.4.3 Interstellar Medium as an Apparent Source

.1	What directionalities do detected cosmic rays exhibit allowing for geomagnetic and solar magnetic field deflections?	SP
.2	Is there an isotropic component, and what are the particle energies?	SP

3.2.1.4.4 Others

.1 What is the typical magnetic field strength in the Galaxy, and the smoothed structure? NS

.2 Are there high-strength magnetic regions in the interstellar medium? NS

.3 What are the field strengths? NS

3.2.1.5 Peculiar IR Sources

3.2.1.5.1 Nebulae as Sources

.1 What is the angular structure of the various peculiar infrared objects at several wavelengths (visible, near, middle, and far IR)? PS

.2 What are the observed coarse spectral energy distributions of the peculiar IR sources? 3-OW

.3 Can a single source account for the distributions (e.g., a blackbody)? AC

.4 How do the IR fluxes vary with time? AC

.5 Is there a secular change, e.g., in the Orion IR objects? AC

3.2.1.5.2 Cool Stars with Dust Shells as Sources

.1 What is the spectrum of peculiar IR objects (particularly the apparently smaller ones) in the visible and near IR wavelength range? PS

.2 Which peculiar IR sources have spectra of late-type stars? 3-OW

.3 What are the indicated distances? NS

.4 What are the observed coarse visible to far-IR spectral energy distributions of the sources (corrected for interstellar absorption where necessary)? PS

.5 Is more than one radiation source indicated? PS

.6 Is there a secular change in the IR fluxes? PS

3.2.1.5.3 Nonthermal Mechanisms as Sources

.1	What is the gross spectral energy distribution of the sources?	PS
.2	Do any distributions fit synchrotron radiation distributions?	NS

3.2.1.5.4 Emission-Line Sources

.1	What is the spectral distribution of the source radiation with somewhat better resolution than presently achieved?	PS
.2	Are IR emission lines indicated as significant contributors to some sources?	AC

3.2.2 UNIVERSE AS A WHOLE

3.2.2.1 Evolutionary Models

3.2.2.1.1 Expanding Universe Models

.1	What is the correct extrapolation of the apparent magnitude — spectral redshift relation to large $\Delta\lambda/\lambda$ for galaxies and quasars?	PS
.2	Are there directional variations in the magnitude-redshift relation?	3-OW
.3	What is the correct apparent magnitude-count relation for galaxies and quasars extended to magnitudes fainter than 24th (red spectral region)?	PS
.4	What is the correct angular diameter-redshift relation for galaxies and quasars extended to large $\Delta\lambda/\lambda$?	PS
.5	Are there directional variations in the angular-diameter-redshift relation?	3-OW
.6	What are the Hubble parameter and deceleration parameter resulting from the above relations?	NS
.7	Is the "cosmic microwave" background isotropic, to better accuracy than currently established?	PS
.8	What is the nature of any anisotropy?	PS

.9 Does the spectral flux distribution fit a 3^{o}K blackbody? AC

.10 Is there evidence for "discreteness" of the background? AC

.11 What are the ages of the oldest stars in Galaxy? NS

.12 What is the mean density of matter in the universe (in particular, a sample in the region of the Local Metagalaxy)? PS

.13 How does the result change when the size of the sample (volume included) is enlarged? AC

3.2.2.1.2 Oscillating Universe Models

.1 What is the correct extrapolation of the apparent magnitude—spectral redshift relation to large $\Delta\lambda/\lambda$ for galaxies and quasars? PS

.2 Are there directional variations? PS

.3 What is the corrected apparent magnitude-count relation for galaxies and quasars extended to magnitudes fainter than 24th (red spectral region)? PS

.4 Are there directional variations PS

.5 What is the correct angular diameter-redshift relation for galaxies and quasars extended to large $\Delta\lambda/\lambda$? PS

.6 Are there directional variations? PS

.7 What are the Hubble parameter and deceleration parameter resulting from the above relations? PS

.8 What are the ages of the oldest stars in the Galaxy? PS

.9 What is the mean density of matter in the universe (in particular, a sample in the region of the Local Metagalaxy)? PS

.10 How does the result change when the size of the sample (volume included) is enlarged? PS

3.2.2.1.3 Steady State Models

.1 What is the correct extrapolation of the apparent magnitude-spectral redshift relation to large $\Delta\lambda/\lambda$ for galaxies and quasars? PS

.2 Are there directional variations? PS

.3 What is the correct apparent magnitude—count relation for galaxies and quasars extended to magnitudes fainter than 24th (red spectral region)? PS

.4 What is the correct angular diameter—redshift relation for galaxies and quasars extended to large $\Delta\lambda/\lambda$? PS

.5 What are the Hubble parameter and decelercation parameter resulting from the above relations? PS

.6 What are the ages of the oldest stars in the Galaxy? PS

.7 What is the mean density of matter in the universe (in particular, a sample in the region of the Local Metagalaxy)? PS

.8 How does the result change when the size of the sample (volume included) is enlarged? PS

.9 Is the "cosmic microwave" background isotropic, to better accuracy than currently established? PS

.10 What is the nature of any anisotropy? PS

.11 Is the background uniform, or does it exhibit angular structure? PS

3.2.2.2 <u>Detailed Processes of the Universe</u>

3.2.2.2.1 Nucleogenesis (Origin of the Elements)

.1 What is the relative abundance of hydrogen, helium, and the heavier elements in the oldest stars as a whole? NS

.2 In the medium-age and young stars? NS

.3 What is the relative abundance of hydrogen, helium, and the heavier elements in the outermost envelopes of old and young stars (coronas or shells of supergiants, planetary negulae, nova and supernova ejecta)? NS

.4 What is the relative abundance of hydrogen, helium, and the heavier elements in interstellar matter? NS

.5 What is the relative abundance of hydrogen, helium, and the heavier elements in nonsolar cosmic rays of low-to-moderate energies, and of high energies? SP

3.2.2.2.2 Galaxy Formation Models

.1 What is the mean density of intergalactic matter? PS

.2 What is the temperature of intergalactic matter? PS

.3 Do clouds of intergalactic matter exist, inside or outside clusters of galaxies? 3-OW,3-LF

.4 What are the densities, sizes, and total mass of any clouds of intergalactic matter? 3-OW,3-LF

3.2.3 ENSEMBLES OF GALAXIES

3.2.3.1 Ensembles of Galaxies as a Whole

3.2.3.1.1 Existence of Second-Order Clustering

.1 What is the highest order of clustering of galaxies? NS

3.2.3.1.2 Clustering as Redshift-Dependent

.1 Is there a variation of clustering tendency with spectral redshift? PS

3.2.3.1.3 Others

.1 What fractions of galaxies are involved in zero-order (noncluster), first-order (clusters), and higher-order clustering (if any)? PS

3.2.3.2 Individual Ensembles of Galaxies

3.2.3.2.1 Large Clusters of Galaxies as Polytropes

.1 What is the mass distribution (galaxies, diffuse matter) in the local group and in certain other large clusters of galaxies? NS

3.2.3.2.2 Diffuse Matter in Clusters of Galaxies

.1 What is the ratio of mass in galaxies to mass in diffuse matter in certain clusters of galaxies? NS

3.2.3.2.3 Small Clusters as Few-Body Systems

.1 What are the internal velocity dispersions in sparsely populated clusters of galaxies? NS

.2 What are the masses of the members of such clusters? NS

.3 What are the sizes of these clusters? NS

3.2.4 INTERGALACTIC SPACE

3.2.4.1 Intergalactic Space as a Whole

3.2.4.2 Intergalactic Ensembles

.1 What is the spatial density of intergalactic globular clusters? PS

3.2.4.3 Intergalactic Discrete Objects

3.2.4.3.1 Quasars

3.2.4.3.1.1 Structure

3.2.4.3.1.1.1 Quasars as Single Objects

.1 Are quasars single objects? PS

.2 What is the absolute size of quasars? AC

.3 What is the mass of a typical quasar? NS

.4 What is the density distribution within quasars? NS

.5 What are the temperature and composition of quasars? 3-OW,3-LF

3.2.4.3.1.1.2 As Composite Objects

.1 Are quasars composites of multiple objects? PS

.2 What are the masses and sizes of the components? NS

3.2.4.3.1.1.3 As Similar to Galaxy Nuclei

.1 How does the structure of a typical quasar compare with nuclei of normal, Seyfert, and other peculiar galaxies? PS

.2 How do the spectra of typical quasars compare with nuclei of normal, Seyfert, and other peculiar galaxies? 3-OW

3.2.4.3.1.2 Radiation Mechanisms, Energy Sources

.1 What is the spectral distribution of radiation emitted by a quasar and/or its subcomponents at all significant wavelengths? PS

3.2.4.3.1.2.1 Thermonuclear Energy Source

.1 What are the distances of quasars? PS

.2 What is the luminosity of quasars? PS

.3 What secular change occurs in the luminosities? PS

3.2.4.3.1.2.2 Gravitational Contraction Energy Source

.1 What are the distances of quasars? PS

.2 What is the luminosity of quasars? PS

.3 What secular change occurs in the luminosities? PS

3.2.4.3.1.2.3 Multiple Supernovae Composite Radiation Source

.1 How does quasar radiation vary with time in short periods? PS

3.2.4.3.1.2.4 Synchrotron Radiation Mechanism

.1 What is the polarization of quasar radiation? PS

3.2.4.3.1.3 Miscellaneous

3.2.4.3.1.3.1 Galaxy-Like Spatial Distribution

.1 What is the true spatial distribution of quasars, and how they are related to individual galaxies and clusters of galaxies? NS

.2 Is the observed spectral redshift entirely of cosmological expansion origin? NS

3.2.4.3.1.3.2 Distribution Localized near Galaxies

.1 Do blue-shifted quasars exist? 3-OW

3.2.4.3.1.3.3 Quasar Redshifts as Gravitational

.1 Can a gravitational redshift account for a significant part of the observed redshift? NS

3.2.4.3.1.3.4 Gravitational Lens Effect

.1 Are the spatial distribution and spatial density of quasars and galaxies such that the "gravitational lens" effect could produce the "quasar phenomenon?" NS

3.2.4.3.1.3.5 Others

.1 Do quasars exhibit any proper motion? NS

.2 What are quasar velocities relative to proximate galaxies? NS

.3 What apparent physical interactions occur between quasars and galaxies? AC

.4 Does an evolutionary sequence of quasars exist, in terms of spectral energy distribution, luminosity, structure, proximity to galaxies, etc. ? NS

.5 What are the ages of quasars ? NS

3.2.4.3.2 Other Discrete Objects

.1 Are there any types of discrete objects other than quasars in intergalactic space ? 3-OS

3.2.4.4 <u>Intergalactic Diffuse Matter and Fields</u>

3.2.4.4.1 Intergalactic Fields

3.2.4.4.1.1 Radiation Field Models

.1 What is the mean electromagnetic radiation density in intergalactic space ? PS

.2 What radiation density is associated with the cosmic microwave background ? UM

.3 What is the typical high-energy cosmic ray energy density in intergalactic space ? SP

3.2.4.4.1.2 Other Fields

3.2.4.4.2 Intergalactic Diffuse Matter

3.2.4.4.2.1 As a Hot Plasma

.1 What are the mean density, temperature and composition of intergalactic diffuse matter ? PS

3.2.4.4.2.2 Condensations in the ingergalactic Medium

.1 Are there condensations in the intergalactic diffuse matter ? PS

.2 What density fluctuations from the mean are involved ? PS

.3 What are the density, temperature, and composition of bridges, filaments, etc., apparently connecting certain galaxies ? 3-OW,3-LF

3.2.5 GALAXIES

3.2.5.1 Galaxies as a Whole

3.2.5.1.1 The Galaxy

3.2.5.1.1.1 Three-Dimensional Mass Models of the Galaxy?

.1 What is the three-dimensional structure of the Galaxy? PS

.2 What are the three-dimensional orbits of stars in the Galaxy (representative types, selected individuals and groups)? NS

3.2.5.1.1.2 Irregular Features

.1 What causes the "hatbrim" and other structural distortions of the Galaxy? NS

.2 Are recently observed "high-galactic latitude clouds" outside or within the Galaxy's corona, gravitationally bound to the Galaxy or not? NS

.3 What are the high-latitude clouds? NS

3.2.5.1.1.3 Nucleus and Corona Models

.1 What are the structure, mass, and composition of the nucleus of the Galaxy? AC

.2 What is the electron density variation with z at moderate and large distances from the galactic plane? 3-LF

.3 What is the gross structure of the galactic corona? PS

3.2.5.1.1.4 Spiral Arm Structure Models

.1 What is the complete spiral arm pattern in the Galaxy? NS

.2 What is the explanation of the spiral arm structure; e.g., is the Lin theory essentially correct? NS

.3 What is the role of magnetic fields in maintaining the spiral structure? NS

3.2.5.1.2 Other Galaxies

3.2.5.1.2.1 Mass Distribution Models

.1 What is the three-dimensional overall structure of selected galaxies? 3-OW

.2 What is the three-dimensional overall structure of the nuclei and spiral arms (if any)? 3-OW

3.2.5.1.2.2 Morphological Types as Evolutionary Sequences

.1 Is there an evolutionary sequence among the galaxies, and if so, what are its characteristics? 3-OW

.2 Do any current classifiation schemes relate to evolutionary sequences? NS

3.2.5.1.2.3 Nearby Galaxies as Satellites of the Galaxy

.1 How do the Magellanic Clouds move relative to the Galaxy? NS

.2 Which other nearby galaxies are satellites of the Galaxy? NS

3.2.5.1.2.4 Internal Evolution in Galaxies

.1 What evolutionary integrated brightness and color changes occur in galaxies? NS

3.2.5.2 <u>Ensembles of Objects</u>

3.2.5.2.1 Stellar Ensembles

C-2

3.2.5.2.1.1 Globular Clusters

3.2.5.2.1.1.1 The System of Globular Clusters in the Galaxy

.1 What are the velocities of globular clusters in the Galaxy? NS

.2 What typical orbits do the clusters follow? NS

.3 Can any clusters escape the Galaxy? NS

3.2.5.2.1.1.1.2 Others

.1 Do the Galaxy's globular clusters have a unique age? PS

3.2.5.2.1.1.2 Individual Clusters

3.2.5.2.1.1.2.1 Stellar Content in Globular Clusters

.1 What is the content of main sequence stars in globular clusters? 3-OS

.2 What are the ages of stars in globular clusters? 3-OS

.3 What is the mean chemical composition of globular cluster stars? PS

3.2.5.2.1.1.2.2 Extragalactic Globular Clusters

.1 What is the relationship of ordinary globular clusters in the Galaxy to peculiar globulars, e.g. the "blue" clusters in the Magellanic Clouds, intergalactic globulars, old galactic clusters? NS

3.2.5.2.1.2 Galactic Clusters

3.2.5.2.1.2.1 The System of Galactic Clusters

3.2.5.2.1.2.1.1 Spatial Distribution as an Age Effect

.1 How are galactic clusters distributed in the Galaxy? NS

.2 What are their galactocentric motions? NS

3.2.5.2.1.2.2 Individual Clusters

3.2.5.2.1.2.2.1 Ages of Galactic Clusters

.1 What are the ages of stars in various galactic clusters? NS

3.2.5.2.1.2.2 Composition of Cluster Stars

.1 What is the chemical composition of stars in clusters of various ages? UM

3.2.5.2.1.2.2.3 Mass Models of Clusters

.1 What is the typical mass distribution in stars and diffuse matter within clusters of various ages? NS

3.2.5.2.1.3 Stellar Associations

3.2.5.2.1.3.1 Associations as a Whole

3.2.5.2.1.3.1.1 Linear Expansion Theory

.1 Is general expansion of associations verified by improved proper motions and radial velocities? NS

.2 Are some loose groups of B stars and supergiants vestigal associations? NS

.3 Do these groups exhibit a unique kinematic age? NS

3.2.5.2.1.3.2 Individual Associations

3.2.5.2.1.3.2.1 Subgroup Structure in Associations

.1 What internal structural regularities are found in OB associations (e.g., presence of multiple stars, "nuclear" galactic clusters, diffuse matter, etc.)? NS

3.2.5.2.1.3.2.2 Star Memberships

.1 What are the internal proper motions and radial velocities of stars in OB associations to somewhat better accuracy than presently established? NS

.2 What improved membership identifications result? NS

3.2.5.2.1.3.2.3 Certain OB Associations as Origins of "Runaway" Stars

.1 What are the radial velocity, distance, and proper motion of O and B "runaway" stars to better accuracy than previously established? NS

.2 Can they be related to OB associations or galactic clusters? NS

3.2.5.2.1.3.2.4 Age Spread in Certain Associations

.1 What are (improved) ages of stars in OB and T associations? NS

3.2.5.2.1.4 Multiple Stars

3.2.5.2.1.4.1 Multiples as a Whole

3.2.5.2.1.4.1.5 Others

.1 What is the mass-luminosity relation for binary stars, and how does this compare with theory for single stars? NS

3.2.5.2.1.4.2 Individual Multiples

3.2.5.2.1.4.2.1 Kepler Orbit Model (Binaries)

.1 What are the improved masses and radii of stars in binary systems? In close versus wide binaries? PS

3.2.5.2.1.4.2.2 Star Content of Multiple Systems

.1 What are the (improved) spectral types, magnitude differences, and luminosities of stars in binaries (especially O and B stars, supergiants)? 3-OW

.2 What is the composition (star types, masses, luminosities, etc.) of stars in high-order multiples found in associations? NS

3.2.5.2.1.4.2.3 Close Binaries as Contact, Detached, Semidetached

.1 In close binary systems, which stars are "proximity-restricted" in evolutionary state? What are their masses and radii? NS

3.2.5.2.2 Solar Systems

3.2.5.2.2.1 The Solar System

3.2.5.2.2.1.1 Solar System as a Whole

3.2.5.2.2.1.1.1 Nebular Origin Model

.1 What are the comparitive ages of Earth, Sun, meteorites, lunar surface material, asteroids, Mars' surface material, etc.? NS

.2 What are the comparative chemical compositions of Earth, Sun, meteorites, planets, asteroids, interplanetary matter, comets? NS

.3 What are the angular momenta of the various solar system bodies? NS

3.2.5.2.2.1.1.2 Sun-Star Encounter Origin Model

3.2.5.2.2.1.1.3 Planet Capture Origin Model

.1	How are the planetary, asteroid, and comet orbits changing with time?	NS
.2	Is there any evidence of secular variations?	NS

3.2.5.2.2.1.1.4 Hydromagnetic-Braking Origin Model

.1	What composition similarities exist among the terrestrial and giant planets, respectively?	PS

3.2.5.2.2.1.1.5 Sun-Planet Interactions

.1	What are the correlations of solar activity (cyclic, active events) with certain planetary phenomena; e.g., terrestrial ionosphere (geocorona) and magnetosphere disturbances, radio emission by Jupiter, the "blue-violet" clearing of Mars' atmosphere, changes in the Red Spot of Jupiter, inner planet accelerations, etc?	NS

3.2.5.2.2.1.4 Planet-Satellite Systems

.1	What structural variations with time occur in Saturn's rings?	PS
.2	Does the correlation of Jupiter's decametric radio emission with the motion of Io occur at lower frequencies?	3-LF
.3	What is the cause of the correlation?	NS
.4	What are improved secular variations in the orbits of Mars' satellites, Jupiter V, and other close planetary satellites?	PS

3.2.5.2.2.1.5 The Planetary System

.1	Does a secular variation in the orbit of Pluto exist?	NS

3.2.5.2.2.3 Other Solar Systems

3.2.5.2.2.3.1 The Solar System as a Model for Others

3.2.5.2.2.3.2 Proper Motion Oscillations Indicating Planets of Nearby Stars

.1 What are the proper motion oscillations of certain nearby dwarf stars having dark companions, to better accuracy than presently established? NS

.2 What orbit elements and masses of the companions are indicated? PS

.3 What additional nearby stars show proper motion oscillations not attributable to visible companions? NS

3.2.5.2.2.3.3 Eclipses of Dwarf Stars by Planets

.1 Do any nearby stars show microfluctuations of brightness possibly indicating transits by unseen companions? PS

3.2.5.3 Discrete Objects

3.2.5.3.1 Stars

3.2.5.3.1.1 Stars as a Whole

3.2.5.3.1.1.1 Theory of Normal Stellar Evolution

.1 What are the evolutionary sequences of stars of all masses from the earliest pre-main sequence phases to latest postfusion phases? NS

3.2.5.3.1.1.2 Significance of Mass Loss

.1 Which stars are ejecting significant mass? 3-OS

.2 What loss rates are involved? NS

3.2.5.3.1.1.3 Effect of Rotation on Evolution

.1 What are the (external) rotation velocities of certain stars (particularly in clusters)? AC

.2 What angular momenta as a function of spectral type are indicated? NS

3.2.5.3.1.1.4 Existence of a Limiting Stellar Mass

.1 Do stable stars more massive than 65 solar masses exist? NS

3.2.5.3.1.2 Prefusion Stars

3.2.5.3.1.2.1 T Tauri Stars

.1 What are the mass, structure, and composition of T Tauri Stars (including associated nebulae) and related objects? 3-OW

.2 What mass accretion and loss occurs? NS

.3 What velocities occur in T Taui nebulae? 3-OW

.4 Are magnetic fields present? NS

3.2.5.3.1.2.2 Wolf-Rayet Stars as Pre-Main Sequence Objects

.1 Where are Wolf-Rayet stars located in the H-R diagram? NS

.2 Are they massive pre-main sequence objects? NS

3.2.5.3.1.2.3 Faintest M-type Dwarfs as Prefusion Objects

.1 What are the masses, effective temperatures, and luminosities of M-type dwarfs? NS

.2 Which are pre-main sequence objects? NS

.3 What is the typical luminosity in "flares" of "flare stars" at UV and IR wavelengths? 3-OP

3.2.5.3.1.3 Fusion Stars

3.2.5.3.1.3.1 Fusion Stars as a Whole

3.2.5.3.1.3.1.1 The Sun as a Whole

3.2.5.3.1.3.1.1.2 Solar Differential Rotation Models

.1 What are the rotation velocities throughout the Sun? NS

3.2.5.3.1.3.1.1.3 Solar Magnetic Field Models

.1 What are the strength and structure of the solar (general) magnetic field, and the temporal variations? NS

3.2.5.3.1.3.1.2 Other Fusion Stars as a Whole

3.2.5.3.1.3.1.2.1 Fusion Star Models

.1 What are the ages and mean chemical compositions of representative normal and selected individual fusion stars? NS

.2 What are the improved mass, structure, luminosity, effective temperature, etc., of typical normal stars of all spectral types? NS

.3 What is the helium content in Population II stars? NS

.4 What is the structure of typical prenovae and presupernovae, and the positions in the H-R diagram? NS

.5 What are the structure and other basic properties of "peculiar A" stars? NS

3.2.5.3.1.3.1.2.2 Pulsating Star Models

.1 What are the pulsation period changes in Cepheids and other variable stars? NS

3.2.5.3.1.3.1.2.3 Magnetic and Rapidly Rotating Star Models

.1 What are the (external) rotation velocities of certain fusion stars (particularly in clusters)? PS

.2 What angular momenta as a function of spectral type are indicates? NS

.3 What are the magnetic fields of selected normal stars? NS

.4 What is the structure of magnetic stars? NS

3.2.5.3.1.3.1.2.4 Effect of Mass Loss

.1 Which fusion stars are ejecting significant mass? PS

.2 What mass-loss rates occur? PS

3.2.5.3.1.3.2 Exteriors of Fusion Stars

3.2.5.3.1.3.2.1 Solar Exterior

3.2.5.3.1.3.2.1.1 Solar Exterior as a Whole

3.2.5.3.1.3.2.1.1.1 Propagation Phenomena

3.2.5.3.1.3.2.1.1.1.1 De Gaston-Ashby Differential Rotation Model

.1 What is the general rotation rate as a function of height and solar latitude? PS

3.2.5.3.1.3.2.1.1.1.2 Corpuscular Radiation Ejection, Transmission Models

.1 What paths do flare-and surge-generated particles of various types and energies follow through the solar atmosphere? PS

.2 What are the trajectories of puffs? PS

.3 What are the creation and attrition rates of flare- and surge-generated particles? PS

3.2.5.3.1.3.2.1.1.1.3 Radio Burst Creation Mechanisms

.1 What is the typical time sequence of the events: flare precursor(s), flare x-ray enhancement, chromospheric emission enhancement, radio burst? 3-LF,3-SO

3.2.5.3.1.3.2.1.1.1.4 Coronal Heating Mechanisms

.1 What energy release is associated with each type of solar active event? 3-LF

3.2.5.3.1.3.2.1.1.1.5 Others

.1 What are the typical quiet Sun matter and wave velocity patterns throughout the atmosphere? AC

.2 What energies and matter flow rates are involved? AC

.3 How do these patterns vary with solar cycle, active events? AC

.4 How is the outward propagation of waves related to active events? AC

3.2.5.3.1.3.2.1.1.2 Structure

3.2.5.3.1.3.2.1.1.2.1 Quiet Sun Structure Models

.1 What are the smoothed quiet Sun vertical density, temperature, and composition distributions? AC

.2 What are the latitude- and longitude-dependent deviations from the smoothed quiet Sun vertical structure and composition? AC

3.2.5.3.1.3.2.1.1.2.2 Temporal Variation of the Structure

.1 How do the density, temperature, and composition vary with the solar cycle and with active events? AC

3.2.5.3.1.3.2.1.1.2.3 Magnetic Field Structure Models

.1 What is the three-dimensional smoothed structure of the general solar magnetic field? PS

.2 How does the field vary with solar cycle and with active events? AC

.3 What is the fine structure of the solar magnetic field, particularly near spots, prominences, flare, coronal condensations, coronal rays and streamers, etc.? AC

3.2.5.3.1.3.2.1.1.2.4 Spectral Line Formation Mechanisms

.1 What is the quiet Sun radiation field throughout the atmosphere? AC

.2 At the photosphere-chromosphere and chromosphere-corona interfaces? AC

.3 What are the spectral line profiles as a function of height in the solar atmosphere? 3-SO

3.2.5.3.1.3.2.1.1.3 Supergranulation

3.2.5.3.1.3.2.1.1.3.1 Existence of Supergranulation Structure

1. Does a supergranulation pattern exist in the solar exterior? 3-SO

3.2.5.3.1.3.2.1.1.3.2 Others

3.2.5.3.1.3.2.1.1.4 Prominences

3.2.5.3.1.3.2.1.1.4.1 Loop Prominence Models

.1 What is the three-dimensional magnetic field structure of a prominence? AC

.2 What matter and energy flows are involved in prominences? AC

.3 What are the temperatures of prominces? AC

3.2.5.3.1.3.2.1.1.4.2 Quiescent Filament Models

.1 Why do solar prominences temporarily disappear? 3-SO

3.2.5.3.1.3.2.1.2 Solar Photosphere

3.2.5.3.1.3.2.1.2.1 Photosphere as a Whole

3.2.5.3.1.3.2.1.2.1.1 Propagation Phenomena

3.2.5.3.1.3.2.1.2.1.2 Structure

.1 What are the quiet Sun average vertical temperature, density, and composition distributions in the photosphere? NS

.2 What is the latitude dependence of the density and temperature variations with height? NS

3.2.5.3.1.3.2.1.2.1.3 Non-LTE Models

.1 What are the Fraunhofer line profiles? AC

.2 What deviation from LTE is indicated? AC

3.2.5.3.1.3.2.1.2.2 Sunspots

3.2.5.3.1.3.2.1.2.2.1 Two-Layer Flow Model

.1 What are the profiles of spectral lines produced in sun spot regions? 3-SO

3.2.5.3.1.3.2.1.2.2.2 Dual Polarity Umbral Structure

.1 What is the magnetic field structure in spot regions? PS

3.2.5.3.1.3.2.1.2.3 Granulation

3.2.5.3.1.3.2.1.2.3.1 Granule Structure Models

.1 What is the apparent (two-dimension) structure of solar granules? 3-SO

.2 Is there a variation with the solar cycle. PS

3.2.5.3.1.3.2.1.2.3.2 Temperature Gradient Modes

.1 What is the temperature distribution across solar granules and intergranular regions? 3-SO

3.2.5.3.1.3.2.1.2.3.3 Granulation Distribution Models

.1 What is the granulation distribution pattern? AC

3.2.5.3.1.3.2.1.3 Solar Chromosphere

3.2.5.3.1.3.2.1.3.1 Chromosphere as a Whole

3.2.5.3.1.3.2.1.3.1.1 Propagation Phenomena

3.2.5.3.1.3.2.1.3.1.1.1 MHD and Shock Wave Motion, Energy Transport Mechanisms

.1 What radial waves propagate through the chromosphere? AC

.2 What lateral waves? AC

.3 Whichare flare precursors or "exciters"? AC

.4 What is the matter flow pattern and rate in the chromosphere? AC

3.2.5.3.1.3.2.1.3.1.1.2 Others

3.2.5.3.1.3.2.1.3.1.2 Structure

3.2.5.3.1.3.2.1.3.1.2.1 Temperature and Density Distribution Models

.1 What is the smoothed chromospheric vertical temperature and density distribution, to get better accuracy than presently known? PS

.2 What latitude and temporal variations occur? PS

3.2.5.3.1.3.2.1.3.1.2.2 Composition Distribution

.1 Does the chromosphere composition vary with position or with the solar cycle? PS

3.2.5.3.1.3.2.1.3.1.2.3 Chromospheric Network Model

.1 What is the structure of the chromospheric network? 3-SO

.2 What is the magnetic field structure, especially near active regions? PS

.3 What is the chromospheric microviscosity? PS

3.2.5.3.1.3.2.1.3.1.2.4 Others

3.2.5.3.1.3.2.1.3.2 Spicules

3.2.5.3.1.3.2.1.3.2.1 Spicule Structure Models

.1 How do the density, temperature, and composition of solar spicules compare with interstitial regions? 3-SO

3.2.5.3.1.3.2.1.3.2.2 Magnetic Focussing Mechanisms

.1 What is the magnetic field around a spicule? PS

3.2.5.3.1.3.2.1.3.3 Plages

3.2.5.3.1.3.2.1.3.4 Flares

3.2.5.3.1.3.2.1.3.4.1 Electrical Discharge Theory

.1 What magnetic and electric fields are present in regions in which a flare occurs? AC

3.2.5.3.1.3.2.1.3.4.2 Thermonuclear Bomb Theory

.1 So solar flare spectra show lines attributable to nuclear reaction products? AC

3.2.5.3.1.3.2.1.3.4.3 Magnetohydrodynamic Models

3.2.5.3.1.3.2.1.3.4.4 Frustrated Surge Prominence Theory

.1 How do the structure, composition, temperature, and energy release of a solar flare compare with surge prominences? 3-SO

3.2.5.3.1.3.2.1.4 Solar Corona (Including Solar Wind)

3.2.5.3.1.3.2.1.4.1 Corona as a Whole

3.2.5.3.1.3.2.1.4.1.1 Propagation Phenomena

3.2.5.3.1.3.2.1.4.1.1.1 Shock Wave Heating Model

.1 Are there shock waves in the corona? PS

.2 What energy do they transmit to the coronal gas? PS

3.2.5.3.1.3.2.1.4.1.1.2 Others

3.2.5.3.1.3.2.1.4.1.2 Structure

3.2.5.3.1.3.2.1.4.1.2.1 Van de Hulst and Ingham-Blackwell Models

.1 What are the smoothed vertical electron and dust density distributions in the corona? AC

.2 How do the electron and dust density distributions vary with the solar cycle? AC

3.2.5.3.1.3.2.1.4.1.2.2 Horizontal Structure Models

.1 How does the electron density distribution vary with latitude and longitude, across rays, streamers, etc? AC

.2 What are the electron densities in coronal condensations? AC

3.2.5.3.1.3.2.1.4.1.2.3 Coronal Magnetic Field Models

.1 What is the general coronal magnetic field, fine structure, cyclical variation? AC

3.2.5.3.1.3.2.1.4.1.2.4 Others

.1 What is the heavy-ion composition and density distribution with height in the corona? AC

.2 What nonradial variations or anomalies are there? AC

3.2.5.3.1.3.2.1.4.1.3 Solar Wind

3.2.5.3.1.3.2.1.4.1.3.1 Hydrodynamic Coronal Expansion Mechanism

.1 What is the typical radial velocity component of the corona at various heights? AC

.2 Does this indicate a general expansion of the corona? PS

.3 How does the expansion velocity vary with the solar cycle? AC

.4 Does the solar wind halt abruptly within the solar system, and if so, where? PS

.5 What are the boundary properties? AC

3.2.5.3.1.3.2.1.4.1.3.2 Others

3.2.5.3.1.3.2.1.4.2 Polar Rays

3.2.5.3.1.3.2.1.4.2.1 Polar Rays as Electron Streams

.1 What is the electron density in polar rays? The temperature? AC

.2 What is the polar ray magnetic-field structure? AC

3.2.5.3.1.3.2.1.4.2.2 Others

3.2.5.3.1.3.2.1.4.3 Helmets and Fans

3.2.5.3.1.3.2.1.4.3.1 Helmets as Electric Loops in Localized Magnetic Fields

.1 What are the electron densities in helmets? The temperature? AC

.2 What is the magnetic field structure around a helmet? AC

3.2.5.3.1.3.2.1.4.3.2 Others

3.2.5.3.1.3.2.1.4.4 Other Features

3.2.5.3.1.3.2.1.4.4.1 Electron Clouds and Rarefactions

.1 Are there distinct electron clouds in the corona? AC

.2 How permanent are they? AC

.3 Are there rarefied regions? AC

3.2.5.3.1.3.2.1.4.4.2 Others

.1 Are there anomalous composition regions in the corona (e.g., where weakly ionized atoms can occur such as Ca II), and if so, what permits them to exist? AC

3.2.5.3.1.3.2.2 Fusion Stars, Exteriors, Other Stars

3.2.5.3.1.3.2.2.1 Exteriors as a Whole

.1 What is the spectral distribution of radiation from normal stars of all types in UV and IR wavelengths? AC

.2 Do any stars show small brightness fluctuations, possibly indicating solar-like spot activity. 3-OP

.3 What is the typical luminosity in flares of flare stars at UV and IR wavelengths? PS

.4 Do any solar-type stars show small brightness fluctuations indicating flare activity? 3-OP

3.2.5.3.1.3.2.2.2 Photospheres

3.2.5.3.1.3.2.2.3 Chromospheres and Coronas

.1 Which stars show "chromospheric" emission lines in the UV? PS

.2 What "chromospheric" structure and temperature are indicated? NS

.3 Which stars show other "circumstellar" spectral lines? PS

.4 What shell structure, temperature, composition, and velocity are indicated? NS

3.2.5.3.1.3.2.2.4 Planetary Nebulae, and Nova and Supernova Ejecta

.1 What is the smoothed structure of certain planetary nebulae, including density inhomogeneities? PS

.2 How is the spatial structure related to emission line-producing regions? PS

.3 What internal velocities occur in planetary nebulae? AC

.4 Differential expansion and rotation velocities? AC

.5 What is the fine spectral distribution of UV and IR radiation by planetary nebulae? 3-OS

.6 What typical chemical composition is indicated? PS

.7 Which nebulae (any morphological type) are previously unrecognized nova or supernova ejecta? PS

.8 What are their densities, masses, structure? PS

.9 What are the indicated centers of expansion and present expansion velocities? NS

3.2.5.3.1.3.3 Fusion Star Interiors

3.2.5.3.1.3.3.1 Solar Interior

3.2.5.3.1.3.3.1.1 Present Sun Interior Model

.1 What is the solar neutrino flux at Earth? NS

3.2.5.3.1.3.3.1.4 Internal Rotation Models

.1 What is the solar oblateness, to greater accuracy than presently established? AC

3.2.5.3.1.3.3.2 Interiors of Other Stars

3.2.5.3.1.4 Postfusion Stars

3.2.5.3.1.4.1 Pulsars

3.2.5.3.1.4.1.1 Rotating Neutron Star Model

.1 What are the pulse period and period changes of pulsars? PS

.2 Do the pulses in pulsars occur in UV or IR wavelengths? 3-OS

.3 What are the size and structure of pulsars (including associated nebulae)? PS

.4 Are pulsars in general co-located with highly peculiar stars? 3-OS

.5 What is the energy emitted in the pulses at various wavelengths? PS

3.2.5.3.1.4.1.2 Pulsating Star Models

.1 What are the pulse period and period of changes? PS

.2 Do the pulses occur in UV or IR wavelengths? PS

.3 Are the pulsars in general co-located with highly peculiar stars? PS

.4 Are any pulsars co-located with white dwarfs? 3-OS

.5 What is the energy emitted in the pulses at various wavelengths? PS

3.2.5.3.1.4.1.3 Others

.1 Are pulsars in general co-located with x-ray sources? PS

.2 What is the polarization of pulsar radiation? AC

.3 Are supernova ejecta found in the vicinity of all pulsars? 3-OS

.4 Do highly peculiar stars exist resembling pulsars (optically identified) that show no pulse behavior? 3-OS

3.2.5.3.1.4.2 White Dwarfs

3.2.5.3.1.4.2.1 White Dwarf Models

.1 What is the UV spectral distribution of the bluer white dwarf radiation? 3-OS

.2 Are there "UV white dwarfs": 3-OS

3.2.5.3.1.4.2.4 White Dwarf Redshifts as Partially Gravitational

.1 What is the nonvelocity (presumably gravitational) reshift in white dwarf binary members to better accuracy than currently established? 3-OW

.2 What mass:radius ratios are indicated? NS

3.2.5.3.1.4.3 Planetary Nebula Central Stars

3.2.5.3.1.4.3.1 Planetary Nebula Central Star Models

.1 What is the spectral distribution of radiation from planetary nebula central stars at UV and IR wavelengths? PS

.2 What are the mass, structure, composition, etc., of these stars? PS

3.2.5.3.1.4.4 Other Postfusion Stars

3.2.5.3.1.4.4.2 Nova, Supernova Remnants

.1 What are the structure and basic properties of nova and supernova remnants? NS

3.2.5.3.1.4.4.3 "Gravitational Holes"

.1 Do any single-line spectroscopic binaries truly lack visible companions, possibly indicating "gravitational hole" secondaries? AC

3.2.5.3.2 Large Bodies

3.2.5.3.2.1 Large Bodies as a Whole

3.2.5.3.2.2 Planets and Large Satellites

3.2.5.3.2.2.1 Planets and Large Satellites as a Whole

3.2.5.3.2.2.1.1 Jupiter's Intrinsic Heat Source

3.2.5.3.2.2.1.2 Transient Events as Volcanic, Outgassing Phenomena

.1 What is the nature of occasional outgassing phenomena on the moon? NS

.2 What causes the color changes? NS

3.2.5.3.2.2.1.3 Others

.1 Is water present on Mars or Venus? PS

.2 What is the Red Spot of Jupiter? AC

3.2.5.3.2.2.2 Interiors

3.2.5.3.2.2.2.1 Major Planet Interior Models

.1 What is the internal structure of Jupiter? The average composition? PS

3.2.5.3.2.2.2.3 Detailed Interior Model of the Moon

.1 What is the internal structure of the Moon, smoothed, and including the mascons? NS

3.2.5.3.2.2.3 Exteriors

3.2.5.3.2.2.3.1 Surfaces

3.2.5.3.2.2.3.1.1 "Craters" on Inner Plants as Impact-Produced, Valcanic

.1 What craters on the moon and Mars were produced by impacts, and by volcanic activity? NS

.2 Does Mercury possess craters, and if so, of which type? 3-OB

3.2.5.3.2.2.3.1.3 Mars' "Wave of Darkening"

.1 What causes the wave of darkening on Mars? NS

.2 What causes the dark band occasionally bordering the polar cap? NS

3.2.5.3.2.2.3.1.4 Large Topographic Irregularities on Mars and Venus

.1 What is the nature of the topographic irregularities on Venus detected by radar, e.g., mountains? NS

.2 What extreme surface-feature elevations occur on Mars? NS

3.2.5.3.2.2.3.1.5 Others

.1 What are the surface-reflected IR spectral distributions from Mercury, Mars, and the large satellites of Jupiter? 3-OB

.2 What surface materials are indicated? NS

3. 2. 5. 3. 2. 2. 3. 2 Atmospheres

3. 2. 5. 3. 2. 2. 3. 2. 1 Detailed Atmosphere Models

. 1 What produces the blue-violet clearning of Mars' atmosphere at certain times? NS

. 2 Is evaporation of a particle layer in the atmosphere involved? NS

. 3 If there a correlation with solar activity (e. g., flares)? NS

. 4 What is the spectral distribution of radiation reflected by the atmospheres of Venus, Mars, Jupiter, and Saturn in the UV? 3-OB

. 5 What emissions are present? AC

. 6 What is the IR spectral distribution (reflected and emitted radiation)? AC

. 7 What are the density and temperature variations with depth below the cloud layers of Jupiter and Saturn? PS

3. 2. 5. 3. 2. 2. 3. 2. 3 Models of the Martian Clouds

. 1 What is the composition of the various cloud types in Mars atmosphere? 3-OB

. 2 What initiation velocities are involved in their formation (i. e., of the moving clouds)? PS

3. 2. 5. 3. 2. 2. 3. 2. 4 Meteorology of Planetary Atmospheres

. 1 What is the meteorology of Venus' atmosphere; e. g., velocity patterns? NS

3. 2. 5. 3. 2. 2. 3. 2. 5 Others

. 1 Does Mercury possess an atmosphere? What are its density and composition? PS

. 2 Is it intrinsic, or merely a trapped condensation in the solar wind? PS

.3 What is the composition of the atmospheres of Uranus and Neptune above their cloud layers, to better accuracy than presently established? AC

.4 Is there water vapor in the atmospheres of Mars or Venus? PS

.5 Is there oxygen in the atmospheres of Mars and Venus? PS

.6 Is there oxygen in Jupiter's atmosphere? AC

3.2.5.3.3 Small Bodies

3.2.5.3.3.1 Small bodies as a Whole

3.2.5.3.3.1.1 Comparative Structure and Composition

.1 How do the structure and composition of comet nuclei, asteroids, and small planetary satellites compare? PS

3.2.5.3.3.2 Comets

3.2.5.3.3.2.1 Icy Conglomerate Nucleus Versus Other Models

.1 What is the structure of a typical comet nucleus, and how does it change during a perihelion passage? PS

3.2.5.3.3.2.2 Tail Structure; Formation and Maintenance Mechanisms

.1 What is the composition (physical, chemical) of the comet head and tail? PS

3.2.5.3.3.3 Models of Subplanetary Bodies

3.2.5.3.3.3.1 Asteroids as Ex-Comets Theory, as Planetary Debris

.1 What is the composition of asteroid material? PS

3. 2. 5. 3. 3. 3. 3 Existence of Microasteroids

. 1 Do microasteroids exist? PS

. 2 Which microasteroids would be favorable for in situ exploration (very near-Earth passage)? NS

3. 2. 5. 3. 3. 3. 4 Existence of Unknown Planetary Satellites

. 1 Are there additional presently unknown small planetary satellites? PS

3. 2. 5. 4 Diffuse Matter and Fields

3. 2. 5. 4. 1 Diffuse Matter

3. 2. 5. 4. 1. 1 Interstellar Diffuse Matter

3. 2. 5. 4. 1. 1. 1 Interstellar Diffuse Matter as a Whole

3. 2. 5. 4. 1. 1. 1. 1 Uniformly Distributed Matter

3. 2. 5. 4. 1. 1. 1. 1. 1 Density Distribution in the Galaxy

. 1 What is the total density of interstellar matter in the solar neighborhood of the Galaxy? NS

. 2 What gradients are evident toward and away from the galactic center? PS

. 3 What is the distribution throughout the galactic disc? NS

. 4 What is the distribution perpendicular to the galactic plane? NS

. 5 What is the typical gas:dust density ratio in the solar neighborhood of the Galaxy? PS

3. 2. 5. 4. 1. 1. 1. 1. 2 Others

3. 2. 5. 4. 1. 1. 1. 2 Nebulae

3. 2. 5. 4. 1. 1. 1. 2. 1 Models of Clouds and Nebulae

. 1 What are the mean density, size, mass, temperature, and composition of clouds in the galactic corona? PS

3. 2. 5. 4. 1. 1. 1. 2. 2 Emission Mechanisms

. 1 What is the IR spectral distribution of interstellar clouds of dust and gas? UM

. 2 What emission lines are present, and what energy loss is involved? AC

3. 2. 5. 4. 1. 1. 1. 2. 3 Globules Models

. 1 What are the mean density, size, mass, temperature, composition, and (in some cases) structure of dense clouds and globules? AC

. 2 What is the spectral distribution of their IR radiation? NS

3. 2. 5. 4. 1. 1. 1. 2. 4 Spatial Distribution of Clouds

. 1 What are their distances from the galactic plane and center? NS

3. 2. 5. 4. 1. 1. 2 Interstellar Gas

3. 2. 5. 4. 1. 1. 2. 1 Diffuse Gas

3. 2. 5. 4. 1. 1. 2. 1. 1 Typical Composition (Atomic and Molecular)

. 1 Does H_2 occur in the intersteller gas? Where? AC

. 2 What are (improved) atomic element abundances in the interstellar gas? PS

.3 What absorption lines does the gas produce in the soft x-ray region? AC

.4 Emissions in the IR? PS

3.2.5.4.1.1.2.2 Gas Clouds

3.2.5.4.1.1.2.2.1 Ionized Cloud Zones

.1 Do HeII ionization zones occur around hot stars, or zones due to heavier elements? PS

3.2.5.4.1.1.3 Interstellar Dust

3.2.5.4.1.1.3.1 Particle Nature Models

.1 What is the nature of typical interstellar dust particles; i.e., composition, size, distribution, shape, density, electromagnetic properties? PS

.2 Are different types present? PS

3.2.5.4.1.1.3.2 Spatial Density Distribution

.1 What is the spatial density of interstellar dust in the solar neighborhood of the Galaxy? AC

.2 What are the density gradients toward and away from the galactic plane? AC

3.2.5.4.1.2 Interplanetary Diffuse Matter

3.2.5.4.1.2.1 Interplanetary Diffuse Matter as a Whole

3.2.5.4.1.2.1.1 Composition and Density

.1 What is the composition (physical, chemical) of interplanetary matter as a function of distance from the Sun (in the ecliptic plane, especially beyond Mars' orbit)? NS

.2 The density distribution? PS

.3 What variations of interplanetary matter composition and density occur out of the ecliptic? AC

3.2.5.4.1.2.1.2 Sources of Interplanetary Matter

.1 What fraction of the interplanetary matter (dust and gas) near the planets is due to the planets themselves? NS

.2 What fraction is true interplanetary matter? NS

.3 Is all of this latter material part of the solar wind? NS

.4 Is part of the Zodical Light or Gegenschein Earth related? NS

3.2.5.4.1.2.1.3 Others

.1 What is the interplanetary gas velocity as a function of distance from the Sun in the ecliptic plane? NS

.2 Does the solar wind "stop" at some distance within the planetary system? PS

.3 What are the gas dynamic properties beyond that distance? NS

3.2.5.4.2 Diffuse Fields

3.2.5.4.2.1 Interstellar Fields

3.2.5.4.2.1.1 Magnetic Fields

3.2.5.4.2.1.1.1 Galactic Disc Magnetic Field Models

.1 What is the large-scale structure of the galactic disc magnetic field, particularly with respect to the spiral arm structure? PS

3. 2. 5. 4. 2. 1. 1. 3 Localized Fields

. 1 What is the typical interstellar magnetic field strength in the solar neighborhood of the Galaxy, to better accuracy than previously established? PS

. 2 Where do relatively high-strength magnetic fields occur in the interstellar medium or diffuse matter? PS

3. 2. 5. 4. 2. 1. 2 Radiation Fields

3. 2. 5. 4. 2. 1. 2. 1 E-M Radiation Field

. 1 What are the typical energy densities of (a) UV stellar radiation above the Lyman limit; (b) IR radiation by stars, nebulae, and interstellar diffuse matter? NS

3. 2. 5. 4. 2. 1. 2. 2 Cosmic Ray Flux

. 1 What is the typical cosmic-ray flux and energy density in the interstellar medium (various particle energies and species), to better accuracy than presently established? SP

. 2 What is the resulting energy supply to clouds of various densities? NS

3. 2. 5. 4. 2. 2 Interplanetary Fields

3. 2. 5. 4. 2. 2. 1 Magnetic Fields

. 1 What are the strengths and structure of the interplanetary magnetic field at various distances from the Sun in the ecliptic plane? PS

. 2 What couplings with local planetary fields occur (i. e., what distortions of strength, structure)? PS

. 3 What are the temporal variations? PS

3.2.5.4.2.2.2 Other Fields

.1 What is the amount of departure from a purely Newtonian gravitational field in the inner solar system? SP

.2 What is the typical solar cosmic ray flux (for various energies and particle species) during flares of various types or importances (a) near Earth, (b) near Venus and Mars? SP

.3 Is there a solar cosmic ray background during active periods? SP

3.2.5.4.3 Diffuse Mixed Matter and Fields

3.2.5.4.3.1 Interstellar Absorption Law

.1 What is the interstellar matter absorption per unit distance at all significant wavelengths (especially UV, IR, x-ray) and in various directions? PS

3.2.5.4.3.2 Interstellar Maser Mechanism

.1 What energy is radiated by interstellar masers? AC

.2 At what wavelengths do presently unknown maser emissions occur? AC

APPENDIX C

RESEARCH CLUSTER DESCRIPTIONS

SPACE ASTRONOMY

Appendix C

INTRODUCTION

This Appendix presents the research clusters identified by the study team of the Earth Orbital Experiment Program and Requirements Study. Each cluster, in general, consists of (1) a narrative synopsis; (2) a list, by number and title, of the critical issues addressed by the research cluster; and (3) a crew activity matrix. Table C-1 identifies these research clusters by number and title.

RESEARCH CLUSTERS

MANNED SPACEFLIGHT CAPABILITY

Cluster No.	Title
BIOMEDICINE	
1-BM-4*	Effects of Weightlessness on Circulatory Function
1-BM-5	Radiation, Toxicology, and Medical Problems
1-BM-6	Effects of Weightlessness on Stress Response
1-BM-7	Effects of Weightlessness on the Nervous System
1-BM-8	Effects of Weightlessness on Gastro-intestinal Function
1-BM-10	Body Fluid Analysis
1-BM-12	Studies on Instrumented Animals
1-BM-13	Effects of Weightlessness on Pulmonary Function
1-BM-14	Effects of Weightlessness on Metabolism
1-BM-15	Centrifuge Studies
BEHAVIORAL RESEARCH	
1-BR-1	Sensory, Psychomotor, and Cognitive Behavior (5 parts)
1-BR-1-1	Visual Experiment
1-BR-1-2	Behavior Effects of Acoustic Environment
1-BR-1-3	Psychomotor
1-BR-1-4	Cognitive Capability
1-BR-1-5	Orientation
1-BR-2	Group Dynamics and Personal Adjustment

---

*Missing numbers were assigned to clusters that were later combined with others or eliminated.

Cluster No.	Title
1-BR-3	Complex Task Behavior
1-BR-4	Skills Retention
1-BR-6	Performance Measurement

MAN-MACHINE RESEARCH

1-MM-1	Controls and Displays
1-MM-2	Locomotion and Restraint
1-MM-3	Habitability
1-MM-4	Work/Rest/Sleep Cycles
1-MM-5	Performance Aids

LIFE SUPPORT AND PROTECTIVE SYSTEMS

1-LS-1	Phase Change and Thermal Processes
1-LS-2	Material Transport Processes
1-LS-3	Atmosphere Supply Processes
1-LS-4	Water Management
1-LS-5	Water Electrolysis
1-LS-6	Food Management and Processes
1-LS-7	Atmosphere Purification Methods
1-LS-8	Life Support Monitoring and Control
1-LS-9	Waste Management
1-LS-10	Heat Transport Equipment
1-LS-11	Crew Equipment and Protective Systems
1-LS-12	Life Support System Maintenance and Repair

ENGINEERING EXPERIMENTS

1-EE-1	Data Management
1-EE-2	Structures
1-EE-3	Stabilization and Control (3 parts)

Cluster No.	Title
1-EE-3-1	Drift Measurement of Gyroscopic Attitude Controls
1-EE-3-2	Disturbance Torque Measurements
1-EE-3-3	Biowaste Electric Propulsion
1-EE-4	Navigation and Guidance (4 parts)
1-EE-4-1	Onboard Laser Ranging
1-EE-4-2	Interplanetary or Translunar Navigation By Spectroscopic Binary Satellite
1-EE-4-3	Landmark Tracker Orbital Navigation
1-EE-4-4	Navigation/Subsystem Candidate Evaluation
1-EE-5	Communications

OPERATIONS EXPERIMENTS

1-OE-1	Logistics and Resupply (2 parts)
1-OE-1-1	Space Logistics and Resupply
1-OE-1-2	Emergency and Rescue Operations
1-OE-2	Maintenance, Repair and Retrofit
1-OE-3	Assembly and Deployment
1-OE-4	Module Operations
1-OE-5	Vehicle Support Operations

SPACE BIOLOGY

VERTEBRATES

2-VB-1	Preliminary Investigations of Biological Processes, Using Primates and Small Vertebrates
2-VB-2	Intermediate Investigations of Biological Processes, Using Primates and Small Vertebrates
2-VB-3	Advanced Investigations of Biological Processes, Using Primates and Small Vertebrates

Cluster No.	Title
INVERTEBRATES	
2-IN-1	Preliminary Investigations of Biological Processes, Using Invertebrates
2-IN-2	Intermediate Investigations of Biological Processes, Using Invertebrates
2-IN-3	Advanced Investigations of Biological Processes, Using Invertebrates
PROTISTS AND TISSUE CULTURES	
2-P/T-1	Preliminary Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
2-P/T-2	Intermediate Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
2-P/T-3	Advanced Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
PLANTS	
2-PL-1	Preliminary Investigations of Biological Processes, Using Plants
2-PL-2	Intermediate Investigations of Biological Processes, Using Plants
2-PL-3	Advanced Investigations of Biological Processes, Using Plants
SPACE ASTRONOMY	
OPTICAL	
3-OW	Optical Structure of Small Extended Sources
3-OB	High-Resolution Planetary Optical Imagery
3-OS	Optical (Faint Threshold) Surveys
3-OP	High Precision Stellar Photometry
3-SO	Optical Studies of the Solar Photosphere and Chromosphere

Cluster No.	Title
X-RAY	
3-XR	Precise Location, Size, and Structure of Known Discrete X-ray Sources, and Existence of Additional Unknown Sources
LOW FREQUENCY RADIO	
3-LF	Location and Properties of Discrete LF Radio Sources, and Structure and Properties of Diffuse Sources
SPACE PHYSICS	
PHYSICS AND CHEMISTRY LABORATORY	
4-P/C-1	Effect of the Space Environment on Chemical Reactions
4-P/C-2	Shape and Stability of Liquid-Vapor Interfaces
4-P/C-3	Boiling and Convective Heat Transfer in Zero-G
4-P/C-4	Effect of Zero-Gravity on the Production of Controlled Density Materials
4-P/C-5	Effect of Electric and Magnetic Fields on Materials
4-P/C-6	The Use of Zero-Gravity to Produce Materials Having Superior Physical Characteristics
4-P/C-7	Improvements of Materials by Levitation Melting
4-P/C-8	Effect of Zero-Gravity on the Production of Films and Foils
4-P/C-9	Effects of Zero-G on Liquid Releases, Size Distribution of Liquid Drops
4-P/C-10	Capillary Flow in Zero-G
4-P/C-11	Behavior of Superfluids in the Weightless State
PLASMA PHYSICS LABORATORY	
4-PP-1	Spacecraft-Environment Interaction
4-PP-2	Energetic Particle Dynamics in the Magnetosphere (3 parts)

Cluster No.	Title
4-PP-2-1	Use of Alkali Metal Clouds as a Space Diagnostic
4-PP-2-2	Use of Electron Beams as a Space Diagnostic
4-PP-2-3	VLF Wave Propagation
4-PP-3	Thermal Plasma in the Ionosphere and Magnetosphere (3 parts)
4-PP-3-1	(Essentially the same as 4-PP-2-1)
4-PP-3-2	(Essentially the same as 4-PP-2-3)
4-PP-3-3	RF Plasma Resonance Studies
4-PP-4	Auroral Processes (3 parts)
4-PP-4-1	(Essentially the same as 4-PP-2-1)
4-PP-4-2	(Essentially the same as 4-PP-2-2)
4-PP-4-3	(Essentially the same as 4-PP-2-3)

COSMIC RAY LABORATORY

4-CR-1	Charge and Energy Spectra of Cosmic Ray Nuclear Component
4-CR-2	Energy Spectrum of High-Energy Primary Electrons and Positrons
4-CR-3	Energy Spectrum and Spatial Distribution of Primary Gamma Rays
4-CR-4	Long-Lived Heavy Isotopes in Cosmic Rays
4-CR-5	Antinuclei in Cosmic Rays
4-CR-6	Quarks (Stable Fractionally Charged Particles) in Cosmic Rays
4-CR-7	Unknown Particles in Cosmic Rays
4-CR-8	Characteristics of Albedo Particles Above 100 MeV
4-CR-9	Nucleon-Nucleon Cross-Sections at High Energies
4-CR-10	Spallation Cross-Sections at High Energies

Cluster No.	Title
COMMUNICATIONS AND NAVIGATION	
NOISE	
5-N-1	Terrestrial Noise Measurements
5-N-2	Noise Source Identification
PROPAGATION	
5-P-1	Ionospheric Propagation Measurements
5-P-2	Tropospheric Propagation Measurements
5-P-3	Plasma Propagation Measurements
5-P-4	Multipath Measurements
TEST FACILITIES	
5-TF-1	Space Deployment and Calibration
5-TF-2	Demonstration and Test
COMMUNICATIONS SYSTEMS	
5-CS-1	MM Wave Demonstration
5-CS-2	Optical Frequency Demonstration
NAVIGATION SYSTEMS	
5-NS-1	Satellite Navigation Techniques for Terrestrial Users
5-NS-2	Laser Ranging
5-NS-3	Autonomous Navigation Systems for Space
5-NS-4	Surveillance Systems
5-NS-5	Collision Avoidance System Techniques
5-NS-6	Search and Rescue Systems
EARTH OBSERVATIONS	
EARTH PHYSICS	
6-EP-1	Photographic Coverage of the Earth
6-EP-2	Identification of Volcanic Activity

Cluster No.	Title

AGRICULTURE, FOREST, AND RANGE RESOURCES

6-A/F-1	Crop Inventory and Land Use
6-A/F-2	Soil Type Mapping
6-A/F-3	Crop Identification
6-A/F-4	Crop Vigor and Yield Prediction
6-A/F-5	Wildfire Detection and Mapping

GEOGRAPHY, CARTOGRAPHY, AND CULTURAL RESOURCES

6-G/C-1	Photographic and Multisensor Mapping

GEOLOGY

6-G-1	Rock and Soil Type Identification
6-G-2	Use of Earth's Crust to Store and Condition Commodities or Waste
6-G-3	Geologic Disaster Avoidance
6-G-4	Utilization of Geothermal Energy Sources
6-G-5	Mineral and Oil Deposit Discovery
6-G-6	Identification of Land Forms and Structural Forms

HYDROLOGY AND WATER RESOURCES

6-H-1	Determination of Pollution in Water Resources
6-H-2	Flood Warning and Damage Assessment
6-H-3	Synoptic Inventory of Major Lakes and Reservoirs
6-H-4	Synoptic Inventory of Snow and Ice
6-H-5	Survey of Soil Moisture in Selected Areas of the North American Continent
6-H-6	Location of Underground Water Sources in Selected Areas
6-H-7	Survey of Hydrologic Features of Major River Basins

Cluster No.	Title
OCEANOGRAPHY AND MARINE RESOURCES	
6-O-1	Ocean Pollution Identification, Measurement, and Effects
6-O-2	Solar Energy Partition and Heating in the Sea Surface Layer
6-O-3	Ocean Population Dynamics and Fishery Resources
6-O-4	Ocean Currents and Tide Forecasting
6-O-5	Ocean Physical Properties
6-O-6	Ocean Solid Boundary Processes
6-O-7	Ocean Surface Activity Forecasting
METEOROLOGY	
6-M-1	Determination of Boundary Layer Exchange Processes Using IR Radiometry
6-M-2	UHF Sferics Detection
6-M-3	Atmosphere Density Measurements by Stellar Occultation
6-M-4	Zero-G Environment Cloud Physics Experiment
6-M-5	Detection and Monitoring of Atmospheric Pollutants
6-M-6	Support of Studies of Special Geographical Areas

RESEARCH CLUSTER SYNOPSIS—ASTRONOMY

3-OW Optical Structure of Small Extended Sources

1. Research Objective

The general objective of this research area is to determine the optical angular structure (dimensions, shapes, and surface details) and spectral distributions (broadband fluxes, spectra) of a variety of apparently small (but nonstellar) objects or sources; namely, remote galaxies; small areas of nearby and moderately distant galaxies (including nuclei); quasi-stellar radio sources (quasars); Bok globules and related optically dense nebulae; comet nuclei; the planets Uranus, Neptune, and Pluto; and the large satellites of Jupiter, Saturn, and Neptune. In all cases, the sources are 10 arc sec in angular extent or less, but some subtend $\ll 1$ arc sec. The chief* specific research objectives are:

1. To obtain spectra and apparent magnitudes (ultraviolet to near infrared wavelengths) of galaxies for extension and clarification of the magnitude-redshift relation, which should permit improved discrimination of competing cosmological theories.

2. To determine optical angular dimensions of quasars (or upper limits), which are important in assessing possible energy sources as well as physical properties of the emitting regions; also to determine the ultraviolet spectra of quasars for additional composition and wavelength-shift data (including searches for blue-shifted objects).

3. To determine angular dimensions of the nuclei of nearby to moderately distant galaxies, and the ultraviolet and infrared (broadband) flux distributions of radiation from the nuclei and from other small areas (e.g., in spiral arms), mainly to elucidate energy sources and emission mechanisms.

4. To determine the radial density distribution of dust in globules and related optically dense nebulae by measuring the optical absorption of background emission within these nebulae, resulting in data that are vital in assessing models of early protostars.

*Some of the research programs of Research Cluster 3-OS can use the observational material obtained in some of the present programs.

5. To determine the apparent internal structure of the nuclei of any comets that make favorable appearances, particularly near perihelion passage when significant structural changes may occur.

6. To obtain very-high-resolution images of the three outermost planets and the large planetary satellites, for determination of the presence of discrete surface or cloud layer features (which can, for example, yield axial rotation rates) and perhaps some improved diameters or oblatenesses.

2. Background and Current Status

Limitations on ground-based observations of remote galaxies for purposes of deriving parameters or relations of cosmological interest have been exhaustively discussed in Reference 1. Current knowledge of the size of the emitting regions of quasars is based largely on radio-frequency interferometry, much less being known about the size of the optical wavelength (ultraviolet, visible, and infrared) emission volume. Ultraviolet spectroscopy of the quasars is beyond the capability of any planned Earth satellite astronomy mission, as is ultraviolet spot photometry of galaxies other than a small number of the nearest, and infrared spot radiometry outside the nuclei. The resolution of galaxy nuclei in visible wavelengths is limited by atmospheric turbulence, meaning that in most cases only upper limits on diameters can be obtained. The atmosphere similarly restricts our ability to resolve the radial structure of most globules or to determine the fine structure of comet nuclei; and less extensively to determine sizes, shapes, and surface detail characteristics of Uranus, Neptune, and Pluto.

3. Description of Research

The types of observations needed here are imagery, photometry, and spectroscopy. The general observational requirements are high angular resolution and faint (flux) thresholds. There is no general rigid resolution requirement stemming from the research objectives, but based on ground- and balloon-based imagery capabilities, <0.1 arc sec is adopted for significant improvement. The flux thresholds that must be attained are more directly defined by the research objectives. For example, objective 1 (above) requires spectra with 1- to 10-Å resolution of galaxies (inner regions only) fainter than visual magnitude 19 (integrated), which is beyond the capability of existing terrestrial instruments.

The above requirements imply the need for a telescope of about 3-m aperture, diffraction-limited at visible, and thus at all longer wavelengths. The design adopted would yield 0.04 arc sec resolution (λ 5,000 Å) on the optical axis and 0.10 arc sec at the edge of its 15 arc minute (diameter) field of view. The nominal focal ratio is f/15 (Ritchey-Chrétien compound optics), but we recommend that the telescope also be operable at prime focus (f/4)

with a field of approximately 1 arc degree. The prime focus capability would be especially valuable for objective 1 and parts of objectives 2 and 3 (listed above) and would render the telescope much more versatile in general.

In addition to the large diffraction-limited telescope, which must be actively guided with extreme precision and have accurate automatic or remotely controlled pointing capability, a number of secondary instruments* are essential to this research area; namely, photographic cameras (prime and secondary focus) with electronic image intensifiers; electronic storage image tubes; a slit spectrograph for ultraviolet, visible, and near infrared wavelengths; an ultraviolet photometer; and an infrared radiometer (with cryogenic cooling apparatus). Other instruments might well be added as experiment definitions become more precise. Of course, both the telescope and secondary instruments would be useful for a variety of observations other than those discussed here.

Because of the great size of the recommended telescope, its launch into Earth orbit as a single unit may not be practical; man may therefore be required to assemble it from several modules. Economic and scientific considerations indicate a long operating lifetime (7 to 10 years) in orbit. This means that man will also be required to perform extensive onboard maintenance, including routine adjustments, secondary instrument exchanges, and some types of damage repair. Observational participation roles for men in orbit have not been fully determined, but may include monitoring and controlling of target acquisitions via short-range television.

4. Impact on Spacecraft

The most significant effect that this research cluster will have on space stations follows from the fact that the recommended telescope should be deployed in a synchronous (19,300-nmi) orbit. This implies the need for well-developed low- to high-orbit or surface to high-orbit manned-vehicle transportation, and possibly for the establishment of a permanent synchronous orbiting manned station. In any case, the telescope must be mounted in a free-flying module, so extensive extravehicular activity (EVA) capabilities are also essential. A telescope control area will be required on the manned station if the target-acquisition problem necessitates man's presence in the observational loop. (See Research Cluster Synopsis 3-OS for additional discussion.)

---

*Secondary instruments for this telescope and those of Research Clusters 3-OS and 3-OB are considered in less detail than the telescopes themselves because of likely changes due to changing scientific emphasis and technological advancements, rendering some currently common instruments obsolete and new instruments more important.

5. Required Supporting Technology Development

The feasibility of constructing a 3-m diffraction-limited optical system must be demonstrated, and a means must be devised to launch its parts safely into orbit. Once the system has been assembled in orbit, there must be proven accurate procedures for aligning and focussing the optical system, preferably by remote control.

The target-acquisition problem associated with large, high angular resolution astronomical instruments in orbit is severe, particularly if we must rely on completely automatic pointing. This deserves very careful study. Additionally, the guidance stabilization requirement is so extreme that the feasibility of meeting it remains to be convincingly demonstrated.

Some supporting research and technology items of less importance are (1) the data-management problem and (2) the utility of photographic versus electronic sensors for the imagery observations. These are discussed briefly in Research Cluster Synopsis 3-OS.

6. References

1. Orbital Astronomy Support Facility Study, Vol. II, Part 2, Section 4.3.1. DAC-58142, June 1968.

2. A Long-Range Program in Space Astronomy. Report of the Optical Astronomy Panel (Position Paper of the Astronomy Mission Board), NASA Publications SP-213, July 1969, pp. 52-53.

Critical Issues Addressed by Research Cluster

3-OW

OPTICAL STRUCTURE OF SMALL EXTENDED SOURCES

3.1.1.1.2.1.3
What are the Doppler shifts of the optical counterparts of x-ray sources?

3.1.1.5.6
What are the angular sizes and structures of peculiar IR sources?

3.1.2.5
What is the apparent magnitude-spectral-redshift relation for galaxies?

3.1.2.6
What is the apparent magnitude-angular-diameter relation?

3.1.2.7
What is the apparent-magnitude-number-density relation?

3.1.3.1.3
Is there a variation of galaxy clustering with increasing spectral redshift?

3.1.4.3.1.1.1
What are the angular sizes and structures of quasars?

3.1.4.3.1.2.1.1
What are the spectral flux distributions and luminosities of the quasars?

3.1.4.3.1.2.1.2
What are the polarizations of quasar radiation? Are there variations with wavelength and time?

3.1.4.4.1.3
Is there an intergalactic magnetic field?

3.1.5.1.2.4
What stellar populations are found in galaxies as a function of types and luminosity?

3.1.5.1.2.6
What is the spectral flux distribution at diverse points in galaxies of various types?

3. 1. 5. 1. 2. 7
What are the rotation velocities at various points in galaxies of various types?

3. 1. 5. 2. 1. 4. 1
What are the orbital elements of a large sample of binary systems, and the indicated masses and radii?

3. 1. 5. 3. 1. 1. 5
What are the properties of suspected prefusion stars?

3. 1. 5. 3. 1. 3. 2. 2. 4. 1
What is the three-dimensional structure of a large sample of planetary nebulae, including inhomogeneities?

3. 1. 5. 3. 1. 4. 1. 3. 1
What are the angular sizes and structures of pulsars?

3. 1. 5. 3. 1. 4. 2. 2
What is the spectral distribution of radiation of white dwarfs?

3. 1. 5. 3. 1. 4. 3. 1
What are the masses, sizes, and spectral distributions of planetary nebula stars?

4. 1. 5. 3. 1. 4. 4. 1
What are the masses, sizes, and spectral distributions of postfusion stars other than pulsars, white dwarfs, and planetary nebula stars?

3. 1. 5. 3. 2. 2. 1. 1
What are the sizes and masses of the planets and large satellites to higher accuracies?

3. 1. 5. 3. 2. 2. 1. 2
What is the oblateness of the planets and large satellites?

3. 1. 5. 3. 2. 2. 1. 5
What are improved sizes and shapes of Uranus, Neptune and Pluto?

3. 1. 5. 3. 2. 2. 3. 1. 10
What is the appearance of the large satellites of Jupiter and Saturn with a few hundred miles of spatial resolution?

3. 1. 5. 3. 3. 2. 1
What are the size, structure, and mass of comet nuclei, and how do these vary during perihelion passage?

3. 1. 5. 4. 1. 1. 1. 1. 2
What are the systematic and turbulent velocities in the interstellar matter in the Galaxy and other galaxies?

3.1.5.4.1.1.1.2.1
What are the masses, size, and structure of bright nebulae?

3.1.5.4.1.1.1.2.2
What are the temperature and composition of bright nebulae?

3.1.5.4.1.1.1.2.4
What are the mass, size, and structure of dark nebulae and clouds?

3.2.1.5.1.2
What are the observed coarse spectral energy distributions of the peculiar IR sources?

3.2.1.5.2.2
Which peculiar IR sources have spectra of late-type stars?

3.2.2.1.1.2
Are there directional variations in the magnitude-redshift radiation for galaxies?

3.2.2.1.1.5
Are there directional variations in the angular diameter-redshift relation?

3.2.2.2.2.3
Do clouds of intergalactic matter exist inside or outside clusters of galaxies?

3.2.2.2.2.4
What are the densities, sizes, and total mass of any clouds of intergalactic matter?

3.2.4.3.1.1.1.5
What are the temperature and composition of quasars?

3.2.4.3.1.1.3.2
How do the spectra of typical quasars compare with nuclei of normal, Seyfert, and other peculiar galaxies?

3.2.4.3.1.3.2.1
Do blue-shifted quasars exist?

3.2.4.4.2.2.3
What are the density, temperature, and composition of bridges, filaments, etc., apparently connecting certain galaxies?

3.2.5.1.2.1.1
What are the three-dimensional overall structure of selected galaxies?

3.2.5.1.2.2.1
Is there an evolutionary sequence among galaxies, and if so, what are its characteristics?

3.2.5.1.2.2.2
Do any current classification schemes relate to evolutionary sequences?

3.2.5.2.1.4.2.2.1
What are the (improved) spectral types, magnitude differences, and luminosities of stars in binaries (especially O and B stars, supergiants)?

3.2.5.3.1.2.1.1
What are the mass, structure, and composition of T Tauri stars (including associated nebulae) and related objects?

3.2.5.3.1.2.1.3
What velocities occur in T Tauri nebulae?

3.2.5.3.1.4.2.4.1
What is the nonvelocity (presumably gravitational) redshift in white dwarf binary members to better accuracy than currently established?

3.2.5.4.1.1.1.2.3.1
What are the mean density, size, mass, temperature, composition, and (in some cases) the structure of dense clouds and globules?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
3-OW B-1	Assemble and Deploy Telescope		5	EVA - Large distance from S/c		5-A	Once only	6 weeks 40-hr wk	3	74		
B-2	Attach and exchange secondary instrumentation and film (cameras, photometers, spectrographs, film)		5	ditto		5-C	1	120-240	1-2			
B-3	Maintain, service, and repair telescope		5	ditto		5-C	1	120-240	1			
B-4	Initiate Data Tacking (Monitor telescope pointing via remore TV, acquire target, turn on instruments)	Console	3	None		6-B	90	30	1			
B-5	Perform optical checkout (Figure, focus, image proporties)	Console	3	None		6-B	13	20-30	1			
B-6	Checkout Acquisition and Guidance System	Console	3	None		6-B	13	30-40	1			
B-7	Checkout Secondary Instruments	Console	3	None		6-B	12	20-30	1			
B-8	Monitor Experimental Observations (Target retained, raw data adequate, signals continuing)	Console	2	None		6-B	270	15	1			
B-9	Remotely control focus and field of view	Console	2	None		6-B	13	10	1			

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS—ASTRONOMY

3-OB High-Resolution Planetary Optical Imagery

1. Research Objectives

This research cluster should be regarded as a skeletal model of a broader program of planetary studies utilizing the high angular resolution capability of large, diffraction-limited, precisely guided, optical telescopes in Earth orbit. The observations described will supplement those made by instruments carried on planetary probes and by ground-based telescopes; i.e., they will cover longer time periods than those of probe missions although with poorer spatial resolution; they will, however, achieve better resolution than long-period ground-based observations. They will make use of Earth-orbiting telescopes that are also available for a variety of nonplanetary observations, instead of requiring additional instruments.

The general objective of this research area is to improve our knowledge of the macroscopic surface properties (i.e., the topography) of Mercury and Mars, especially including changes in surface features. In the case of Mars, there is added interest in atmospheric features (clouds, hazes) and their temporal variations (meteorology). More than any other research cluster described in the Astronomy section of this study, this one has a direct, practical bearing on the NASA space (in situ) exploration program.

2. Background and Current Status

Prior to 1965, our knowledge of the Martian topography was based on photographs taken with ground-based telescopes, which showed features no smaller than 0.5 arc sec (corresponding to approximately 140 km at close opposition distance), and on visual observations revealing detail sometimes as small as 0.2 arc sec (60 km) but difficult to accurately record. The Mariner flyby of that year sent back several TV pictures showing detail in areas of the surface as small as 2 to 3 km, mainly craters—whose existence (if not their abundance) had been long ago asserted by some visual observers. The 1969 Mariner VI and VII missions returned a much larger number of pictures, including whole-disk TV photographs, with resolution ranging from about 10 to 1 km. Among the important findings from these remarkable pictures (which are still under intensive study) are that some of the prominent Martian "oases" seen from Earth are very large craters, and that the brightness differences between the deserts is due to different areal densities of the craters plus

differences in the crater reflective properties. There are indications that the dark areas (maria) also differ from the deserts because of different crater properties in the respective regions, and that the wave of darkening is caused by changing reflective properties in the crater floors. Relatively bright material (CO_2 snow?) has been found on some inner crater rims in both the 1965 and 1969 Mariner pictures.

Additional Mariner flybys and Viking orbiter-lander missions are planned for 1971 to 1975. These are expected to return still sharper pictures than the past Mariner as well as providing much longer temporal coverage (Viking). Whether the timing of these missions and their observing lifetime will be fortuitous or long enough to provide good synoptic coverage of changes in surface detail (abrupt, short-period, seasonal, and long-period) and atmospheric phenomena is sufficiently doubtful that supplementary imagery observations with large optical telescopes in Earth orbit are proposed. Such observations would become backups to the probe missions in the event of failures (or cancellations) of the latter. They can reveal Martian detail as small as approximately 10 km at closest approach to Earth. Although this is much poorer than possible for probe TV cameras, it is much better than ground-based capability.

In the case of Mercury, there is considerably more need for high-resolution observations by Earth-orbiting instruments than for Mars, since knowledge of the Mercurian surface characteristics is poorer and only one flyby probe mission (1973-74) is planned. It is not possible that the flyby TV cameras will record more than 50 percent of the planet's sunlit surface even if it is highly successful; whereas during an 8 month period, an Earth-orbiting telescope could be used to map virtually the entire surface (the extreme polar regions excluded) with resolution as good as 20 to 40 km. Repeat observations would, for the first time, show whether there is any significant activity on Mercury's surface (e.g., vulcanism). Though not emphasized in the Research Cluster Description (Appendix C), sequences of photographs at several wavelengths in the 2,000-Å to 1-μ range might show evidence of a tenuous atmosphere, e.g., in the form of reduced surface feature contrast at the shorter wavelengths due to atmospheric scattering.

3. Description of Research

Two telescopes are recommended for this work, a (first-generation) 1-m aperture instrument and a (second generation) 3-m aperture instrument, both with optics figured to give diffraction-limited image quality on their optical axis. These are the same telescopes that are associated with Research Clusters 3-OS and 3-OW, respectively. For the present observations, they would be used with amplifying lenses at the secondary foci, yielding effective focal ratios of f/75. The resulting image diameters would be 3 to 27 mm for Mars and 2 to 9 mm

for Mercury when most favorably located for observing, permitting use of moderate resolution imaging media without seriously degrading the net resolution. Because of the severe guidance precision also required to avoid resolution degradation plus the inevitably long photographic-exposure times necessitated by large image sizes, the imaging device used (with either telescope) will be a photographic camera with electronic image intensifier or a pure electronic (TV) camera. Although the extent of the observing programs will be dictated by what is specifically discovered during the early phases, it is expected that at least 1,000 good images of the two planets (in four or five colors) will be obtained.

The role of man in connection with these observations is related to the deployment and servicing of the telescopes. (See Experiment Group Descriptions 3-OS and 3-OW.) If photographic image recording is employed, the importance of the servicing function (i.e., film or plate changing) would be heightened. The observations (including target acquisition) will be made automatically or through remote control.

4. Impact on Spacecraft
The impact that this research will have on the space stations is discussed in Research Cluster Synopses 3-OS (1-m telescope) and 3-OW (3-m diffraction-limited telescope).

5. Required Supporting Technology Development
The supporting research and technology required by this cluster are the same as the support requirements described in Research Cluster Synopses 3-OS and 3-OW.

Critical Issues Addressed by Research Cluster

3-OB

HIGH RESOLUTION PLANETARY OPTICAL IMAGERY

3.1.5.3.2.2.3.1.7
What long-term surface feature changes occur on Mars at 10- to 50-mi spatial resolution?

3.1.5.3.2.2.3.1.9
What is the appearance of Mercury at 50-mi spatial resolution?

3.1.5.3.2.2.3.2.1
What is the meteorology of Mars with 10- to 50-mi spatial resolution?

3.1.5.3.2.2.3.1.2
Are volcanic activity and outgassing presently occurring on Mars' surface? Where?

3.1.5.3.2.2.3.1.13
Are there mountain chains on Mars or Mercury?

3.1.5.3.2.2.3.2.7
What are the density and composition of Mercury's atmosphere?

3.2.5.3.2.2.3.1.1.1
Does Mercury possess craters, and if so, of which type?

3.2.5.3.2.2.3.1.5.1
What are the surface-reflected IR spectral distributions from Mercury, Mars, and the large satellites of Jupiter?

3.2.5.3.2.2.3.2.1.4
What is the spectral distribution of radiation reflected by the atmospheres of Venus, Mars, Jupiter, and Saturn in the UV?

3.2.5.3.2.2.3.2.3.1
What is the composition of the various cloud types in Mars' atmosphere?

RESEARCH CLUSTER
NO. 3-OB

Table 1
CREW ACTIVITY

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
3-OB -1	Inspect Optical Surfaces Before Separation	Sensors	3		X	5-B		* Task times repeat for each of the two major instruments - except assembly in orbit, one only.				
-2	Monitor Deployment	TV Monitor	3		X	5-B	1	2 hrs.				
-3	Monitor Optical Surfaces Remotely	Optical Sensors	5			6-B	1					
-4	Align Optics After Deployment	TV Monitor, Sensors	4		X	6-A	1	21 Hrs				
-5	Calibrate Electro-Optical Detectors	Detectors	4			6-B	1					
-6	Monitor Pointing Accuracy	TV Monitor	5		X	6-A						
-7	Select Analyzer-Detector Remotely		5		X	6-A						
-8	Inspect and Maintain Telescope (Scheduled)		4	(?EVA)	X	5-B	As Req.	6 hrs/yr				
-9	Repair (Unscheduled)		4	(?EVA)	X	5-B						
-10	Assemble in Orbit	PSA	3	EVA	X	5-B	1	12 hrs				

†See Legend of Codes, next page. ‡ X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS--ASTRONOMY

3-OS Optical (Faint-Threshold) Surveys

1. Research Objectives

The general objective of this program is to observe a variety of faint known objects in ultraviolet, visible, and near-infrared wavelengths. Depending on the objects involved, the observations will be used for detection, precise position determination, angular diameter measurement, and brightness measurement. The type of objects representatively described are (1) main-sequence stars in globular star clusters; (2) Cepheid variable stars in moderately distant galaxies; (3) HII regions in moderately distant galaxies; (4) "optical counterparts" of discrete x-ray sources (radio), pulsars, some peculiar infrared and radio sources, and "empty" emission nebulae; and (5) unknown planetary satellites. Specific research objectives associated with the objects listed above are as follows:

1. To extend the observed color-magnitude diagrams of a good sample of globular clusters to include the main sequence to spectral type K, and to use the results tegether with stellar model data to obtain cluster ages (from the main-sequence turnoff). These ages will then be compared with determinations based on giant-branch fitting to derive improved and self-consistent values. Implications of the main-sequence data concerning cluster chemical composition, RR Lyrae and giant-star-member absolute magnitudes, and dynamical models of globular clusters will also be investigated.

2. To obtain two- or three-color photometry (from photographs; e.g., with U, B, V filters) of Cepheid variable stars in galaxies beyond the local group, with sufficient precision and time coverage to determine light curves and hence variation periods. From the period-luminosity-color relation and the measured apparent magnitudes, the distance to the parent galaxies will be derived. Individual distance determinations to galaxies (including members of clusters of galaxies) will be extended to distances of some tens of megaparsecs (mpc) with particular attention to the most astrophysically interesting objects. The composite results will also be used to improve calibrations involved in distance estimates based on brighter objects; e.g., early- and late-type supergiants, and HII regions.

3. To detect, identify, and measure angular diameters of HII regions in galaxies between 10 and 100 MPC distant (photographically observed); to combine angular diameters with expected absolute diameters (e.g., for the brightest, nth brightest, or average HII regions) to derive distances of the parent galaxies. Concentrate observations on astrophysically interesting galaxies, and galaxies with good, bright Cepheid populations. Apply composite distance determinations to the large-distance calibration problem as in (2).

4. To search the fields of discrete x-ray sources, pulsars, etc. to discover the associated optical (ultraviolet and visible wavelengths) objects, where ground-based observations fail, and to determine whether some sort of star is involved in all cases. Following successful identifications, photometric and possible spectroscopic observations would be made to elucidate the physical nature of the sources.

5. To search the fields of the outer planets (as recorded photographically) for additional unknown satellites. This census-taking program is recommended only as a by-product of more-important planetary imagery studies; i.e., if and when suitable (long-exposure) planet-field photographs were produced, they could be examined by interested investigators for new satellites.

6. In the course of galaxy, globular cluster, or optical counterpart observations, the presence of additional objects may be discovered, such as microasteroids and planets beyond Pluto. As in the case of Item 5 (above), e.g., intergalactic globular clusters, this is a by-product program with highly unpredictable results. Also of interest would be the discovery of new types of galactic objects, but the nature of these is wholly uncertain.

2. Background and Current Status

All the observations described here can be performed within certain limits from the ground, and some might be improved using OAO-class automated optical telescopes and appropriate detectors. However, we are considering substantial advancements in observational capability; i.e., to photographic magnitude limits of 26 to 28, angle-measurement precision to < 0.2 arc sec, and accurate photometry to magnitudes (visible wavelengths) of > 24. Because ground-based telescopes have poorer capabilities, it is currently possible, for example, to resolve and measure upper main-sequence stars in only a few of the nearest globular clusters, and to apply Cepheids and HII regions as distance indicators in galaxies to distances of only 4 and 10 MPC, respectively. Optical counterpart discoveries have been few and often disputed. At the very least, an increased

detection threshold offers the prospect of enlarged candidate samples, which by intercomparison might resolve many controversies.

As for new solar system objects, they are understandably uninteresting to the Earthbound astronomer. Microasteroids and other debris appear more important as spaceflight hazards than as objects to study, although in situ exploration of small bodies passing near the Earth could provide composition information bearing on the origin of the solar system.

3. Description of Research

This research program involves the launch into low Earth orbit of, first, a 1-m-aperture diffraction-limited optical telescope, and then, a 3-m instrument having the angular resolution capability (but three times the light-gathering power) of the 1-m telescope. Among the complement of secondary instruments that these general-purpose telescopes would accommodate are photographic cameras and electronic imaging devices (e.g., vidicons) that would be used to perform the present observations. As a starting observation program, it is recommended that some 20 globular clusters, 50 galaxies, and 40 additional selected fields by photographed (or electronically recorded). This minimum program would be undertaken, using the 1-m telescope and later the 3-m telescope as collectors.

Undoubtedly, the early results will warrant program expansion. All observational data (i.e., photographic film or plates, or electronic images) would be studied at ground observatories, using appropriate measuring equipment (photographic photometers and angle-measuring machines).

Men will probably be required to participate directly (in orbit) in the assembly and deployment of the 1-m first generation telescope, and certainly for the 3-m instrument. A number of scheduled maintenance tasks for men have been specified in the Research Cluster Description; it is also clear that the lifetime of these expensive telescopes could be significantly extended if unscheduled maintenance (i.e., damage repair) is feasible.

4. Impact on Spacecraft

The telescopes must be located in free-flying modules at some distance from any manned station, to minimize guidance stability problems and to avoid the station effluent corona. The above tasks thus imply advanced EVA capability. Observations would be automatic although human control of target acquisition via the remote TV monitor and control of the telescope drive are distinct possibilities. This means that an astronomy command-control post on the manned station is likely to be required.

5. Required Supporting Technology Development

Although it appears that 1-m primary aperture diffraction-limited optical systems can be fabricated on Earth, it is less certain that the same figure quality can be achieved in a 3-m mirror (i.e., the primary of the non-diffraction-limited telescope considered here). Additionally, the stability of mirror figures during launch into orbit must be guaranteed, and once in orbit there must be means of maintaining the figures in nominal conditions; e.g., against distortions resulting from thermal fluctuations in the mirror material. As for the total optical systems, precision alignment and focusing procedures must be developed, including testing methods that can be applied in orbit. That a substantial number of designs for 1-m-class orbital optical telescopes have been produced by various organizations suggests that problems of the type discussed above have not been altogether successfully solved.

The guidance-stabilization accuracy required for these telescopes is extremely high—one order of magnitude better than in any remotely controlled (or automatic) space telescope yet flown, and two orders better than any orbital instrument flown or planned. It is impossible to overemphasize the fact that, if the specified guidance accuracy cannot be achieved, the entire research cluster described here will become pointless, since detection thresholds will deteriorate to the range of ground-based telescope. Quite apart from the guidance problems is the matter of target acquisition, which has not received sufficient study. Questions that need resolving include:

1. How, exactly, will large space telescopes be pointed to precisely center a single star, planet, nebula, or galaxy in the field of view (which may be only a few arc min in diameter)?

2. How will discrete objects (stars and nebulae) in dense clusters and galaxies be positioned on the extremely small spectrograph slits (or photometer diaphragms) needed to realize diffraction-limited optical performance?

Finally, among the major supporting research and technological problems associated with large space telescopes, there is the data-management problem. A major and persistent element of this problem is determining whether photographic, electronic, or hybrid image recording will be employed. Either alternative involves data-transmission problems; namely, film supply and handling and in-orbit versus ground-based development in the case of photography; and telemetry rates and transmission power requirements in the case of electronic (TV) imagery. Despite a considerable amount of invested study effort to date, conclusions indicating firm decisions as to optimum imagery techniques are still lacking.

6. References

There is no unified discussion in the astronomical literature of the scientific objectives or material in this research cluster. Items (1), (3), and (4) in Section 1, were taken from the Orbital Astronomy Support Facility Study, Vol. II, Part 1, DAC-58142, June 1968, pp. 152-3, 162-3 and 166-7. Items (1), (4), and (5) are mentioned in the report of the Optical Astronomy Panel, A Long Range Program in Space Astronomy (Position Paper of the Astronomy Missions Board, NASA Publ. SP-213), July, 1969, pp. 46 to 76.

Critical Issues Addressed by Research Cluster

3-OS

OPTICAL (FAINT THRESHOLD) SURVEYS

3. 1. 1. 5. 2
What are the optical counterparts of certain peculiar IR sources?

3. 1. 1. 5. 4
How does the radiation of peculiar IR sources vary in time?

3. 1. 1. 5. 5
What is the polarization of peculiar IR sources?

3. 1. 1. 6. 1
What presently unknown types of astronomical sources or objects exist?

3. 1. 4. 2. 1
What is the spatial (number) density of intergalactic globular clusters?

3. 1. 5. 1. 2. 8
What are improved distances of galaxies beyond 10 megaparsecs?

3. 1. 5. 2. 1. 1. 1
What is the structure of globular clusters?

3. 1. 5. 2. 1. 1. 2
What is the chemical composition of globular cluster stars?

3. 1. 5. 3. 1. 4. 1. 1. 2
What are the optical counterparts of pulsars?

3. 1. 5. 3. 1. 4. 1. 1. 3
What are the apparent proximities of pulsars to discrete x-ray sources?

3. 1. 5. 3. 1. 4. 1. 2. 2
What are the spectral flux distributions of the pulsars as a function of time in pulses and between pulses?

3. 1. 5. 3. 3. 3. 2
Do microasteroids exist, and if so, what are their masses and sizes?

3.1.5.3.3.3.7
Do any of the planets possess presently unknown satellites?

3.1.5.3.3.4.1
Are there presently unknown types of small bodies in the solar system?

3.1.5.4.1.1.2.2.4
What are the apparent sizes of HII regions in galaxies in the 10- to 100-mpc distance range?

3.2.1.1.1.3.1
What are the apparent proximities of x-ray sources to known supernova ejecta, or shells?

3.2.1.1.1.4.1
Are x-ray sources co-located with some galaxies?

3.2.1.1.1.5.1
Are x-ray sources co-located with nebulae?

3.2.1.2.1.1.1
Are stars co-located with any discrete gamma-ray sources?

3.2.4.3.2.1
Are there any types of discrete objects other than quasars in intergalactic space?

3.2.5.2.1.1.2.1.2
What are the ages of stars in globular clusters?

3.2.5.2.1.1.2.1.3
What is the mean chemical composition of globular cluster stars?

3.2.5.3.1.3.2.2.4.5
What is the fine spectral distribution of UV and IR radiation by planetary nebulae?

3.2.5.3.1.4.1.1.2
Do the pulses in pulsars occur in UV or IR wavelengths?

3.2.5.3.1.4.1.1.4
Are pulsars in general co-located with highly peculiar stars?

3.2.5.3.1.4.1.2.4
Are any pulsars co-located with white dwarfs?

3.2.5.3.1.4.1.3.3
Are supernova ejecta found in the vicinity of all pulsars?

3.2.5.3.1.4.1.3.4
Do highly peculiar stars exist resembling pulsars (cptically identified) that show no pulse behavior?

3.2.5.3.1.4.2.1.1
What is the UV spectral distribution of the bluer white dwarf radiation?

3.2.5.3.1.4.2.1.2
Are there "UV white dwarfs"?

Table 1
CREW ACTIVITY MATRIX

RESEARCH CLUSTER
NO. 3-OS

EXPERIMENT GP/SUB GP	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	[illegible]†	SPECIAL ENVIRONMENTAL [illegible]	FULL-TIME‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK SEQUENCE†
3-OS -1	Inspect Optical Surfaces Before Separation	Sensors	3		X	5-B		* Task times repeat for each of two major instruments - except assembly in orbit, one only				
-2	Monitor Deployment	TV Monitor	3		X	5-B	1	2 hrs				
-3	Monitor Optical Surfaces Remotely	Optical Sensors	5			6-B	1					
-4	Align Optics After Deployment	TV Monitor, Sensors	4		X	6-A	1	21 hrs				
-5	Calibrate Electro-Optical Detectors	Detectors	4			6-B	1					
-6	Monitor Pointing Accuracy	TV Monitor	5		X	6-A						
-7	Select Analyzer-Detector Remotely		5		X	6-A						
-8	Inspect and Maintain Telescope (scheduled)		4	(?EVA)	X	5-B	As Req.	6 hrs/yr				
-9	Repair (unscheduled)		4	(?EVA)	X	5-B						
-10	Assemble in Orbit	PSA	3	EVA	X	5-B	1	12 hrs				

†See Legend of Codes, next page. ‡ X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS--ASTRONOMY
3-OP
High Precision Stellar Photometry

1. Research Objectives

Among the astronomical problems for which high-precision (necessarily photoelectric) photometry could provide crucial data are:

1. Microfluctuations in brightness indicating flare and/or sunspot activity in the atmospheres of some stars.

2. Periodic microfluctuations in the observed flux density of nearby dwarf stars due to transits by planetary companions, where the geometry is ideal. Also, flux variations in barely eclipsing binary stars, yielding improved orbit inclinations and more thorough statistics on binaries.

3. Secular variations in magnitude and/or color of massive stars in rapid evolutionary phases, a direct test of stellar evolutionary theory and possible means of obtaining new mass and radius values.

4. Variability of stars flanking instability (Cepheid, βCMa, etc.) strips in the HR diagram, to determine time scales for onset and cessation of pulsation or other variation mechanisms.

Another advanced observational category somewhat related to the above is photometry of lunar occultations of stars, which requires good photometric precision plus very high time resolution by the detection system. Such measurements can yield stellar angular diameters, reveal close binaries, and indicate lunar limb features sizes and slopes. In conjunction with very precise lunar orbit and geometrical figure data (which appear within our grasp), it is also possible to determine trigonometric parallaxes of some stars. Although there is no question that occultation observations would be better made in space than on Earth, unresolved problems regarding the satellite orbit altitude and motion plus the lack of definitive information on the possible scope of such observations in space necessitated omission of this topic from detailed consideration in the present study.

2. Background and Current Status

Because of the extreme photometric precision required for this research (Items 1 through 4 above), practically nothing has been done to date. The closest relevant areas of current research are

stellar polarimetry (on the basis of precision), and studies of ultrashort-period star variability and small amplitude flare stars. See also Subsection 3 below.

3. Description of Research
Observations of the above type require photometric accuracy on the order of 10^{-4} magnitude as a beginning, a precision only approached in ground-based stellar polarimetry by using the two-cell differential photometry technique. Ordinary photoelectric photometry is limited to $\sim 10^{-3}$ magnitude by atmospheric density and temperature fluctuations ("sky noise"), detector noise, and the long integration times required. In space much better precision should be attainable, though improved low-noise photometers will have to be developed and new observing techniques (such as star-comparison star rather than star-sky difference measurements) may be required. Optimum observational sampling procedures need to be devised to avoid continuous, excessively time-consuming monitoring of large numbers of stars to seek rare events such as "shallow" partial eclipses and planet transits. Finally, data processing methods to discriminate small-amplitude periodic (eclipses, transits), near-periodic (sunspots), and random (flares) fluctuations in observed signals are essential. Any of the three large optical telescopes of research clusters 3-OS and 3-OW would be suitable for the observations considered here.

4. Impact on Spacecraft
Same as for research clusters 3-OS and 3-OW.

5. Required Supporting Technology Development
Same as for research clusters 3-OS and 3-OW, plus the requirements relating to low-noise photometers, sampling procedures, and data processing mentioned in Item 3 above.

6. References
Orbital Astronomy Support Facility, Vol II, Part 2 (DAC-58142), 1968, pp 153-155.

Critical Issues Addressed by Research Cluster

3-OP

HIGH PRECISION STELLAR PHOTOMETRY

3.1.5.2.2.3.3
Do any nearby dwarf stars exhibit periodic brightness microfluctuations, possibly indicating transits by "dark" companions?

3.2.5.3.1.2.3.3
What is the typical luminosity in "flares" of "flare stars" at UV and IR wavelengths?

3.2.5.3.1.3.2.2.1.2
Do any stars show small brightness fluctuations, possibly indicating solar-like spot activity?

3.2.5.3.1.3.2.2.1.4
Do any solar-type stars show small brightness fluctuations indicating flare activity?

RESEARCH CLUSTER SYNOPSIS--ASTRONOMY
3-SO
Optical Studies of the Solar Photosphere and Chronosphere

1. Research Objectives
This research area is concerned with the fine physical structure of the solar photosphere and chromosphere as revealed by high angular and high spectral resolution observations at visible and ultraviolet wavelength (1000Å to 1μ, approximately). Specific research objectives may be grouped as follows:

1. To better determine gross physical properties of the quiet photosphere and chromosphere, such as temperature and magnetic field distributions, using new or improved visible and UV observations.

2. To determine the fine physical structure and obtain spectra of small photosphere and chromosphere features, e.g., sunspots, plages, prominences, spicules.

3. To better determine properties of prominent active events (flares and related phenomena) and to elucidate temporal interrelationships of these phenomena.

2. Background and Current Status
All of the critical issues (or above research objectives) addressed by this research cluster can be treated to some extent by combining ground-based, aircraft, rocket, and unmanned satellite observations. However, these observations are generally either capable of good angular resolution while limited to mediocre spectral resolution (especially in the UV), or vice versa.

3. Description of Research
The three chief types of observations appropriate here are (a) broadband high resolution imagery ($\approx$0.1 arc-sec at λ5000Å to 0.5 arc-sec or better at 1000Å), including cinematography; (b) monochromatic imagery (passband centered on some prominent spectral line such as Hα) with good angular resolution; (c) high dispersion spectroscopy, resolution 0.01Å or better, with angular resolution of a few arc-sec. The duration of observations, or repetition periods, will range from seconds (prominent active events) to years (solar cycle variations of physical properties).

The principal instrument for this research cluster is a Gregorian-optics telescope of 1.5-m (60-in) aperture and 75-m effective focal length (f = 50). The primary mirror has a focal ratio of 3.6, and the secondary magnifies 14 times. The Gregorian focal plane lies 0.3 m (12 inches) behind the primary mirror, permitting access via rotating mirror by a variety of large, specialized

secondary instruments, including a 1500- to 10,000 Å triple-range echelle spectrograph, a slit-jaw movie camera (for simultaneous ultraviolet-visible imagery of areas being observed spectroscopically), a vidicon camera for field imagery and target acquisition and guidance monitoring, and one or two (Leighton or Babcock) solar magnetographs. The total instrument is 13.5 m long and about 2.5 m in diameter.

With this telescope, coarse solar-disk acquisition would be accomplished automatically by an auxiliary sun sensor, which will bring the disk into the field of a guide telescope having a TV camera for remote monitoring. Using this intermediate acqusition system, a specific area of interest on the disk can be targeted to within ±0.5 arc-sec for very high resolution spectroscopy, ±0.5 to 2.5 arc-sec for high to moderate resolution spectroscopy*, and ±15 arc-sec (approximately) for imagery. The telescope will achieve diffraction-limited angular resolution at λ6000 Å (0.1 arc-sec) and longer wavelengths, but will be somewhat poorer in performance in ultraviolet wavelengths. Five guidance will be controlled automatically from a limb sensor, or by a remote observer using the TV camera at the Gregorian focus. Control-moment gyros will provide the pointing stabilization and slewing drives.

4. Impact on Spacecraft
Deployment of the telescope will be largely automatic, and optical alignment and electromechanical calibration will be remotely monitored and controlled, using servo motors for adjustments. Maintenance and repair tasks for the crew will include replacement of worn components and malfunctioning or damaged cameras, electronics, or motors. Replacement and change of film, and possibly spectrograph gratings, will also be required at the telescope. Most noteworthy, however, is the extensive involvement of man as an observer. Unlike the other Space Astronomy research clusters considered in this study, in investigator would select, in real time, specific solar phenomena or details on the basis of scientific importance and observe the development of these features, as well as performing more routine acquisition and guidance tasks. The implication of this requirement for crew-skill assessments is that a solar astronomer will be needed to participate directly in the observations. However, it is not certain whether this man must be located in orbit, since remote control from Earth could be feasible if data transmission rates and related power requirements are not excessive. Finally, the solar telescope, for optimum observational efficiency, should be located in a sun-synchronous Earth orbit.

*These values correspond to the entrance slit widths for 0.002 and 0.02 to 0.1 Å resolution at λ3000 Å, respectivey, using the proposed spectrograph.

5. Required Supporting Technology Development
The STD items for this research cluster, mainly concerned with the solar telescope itself, are generally the same as for the optical telescopes described in research clusters 3-OW and 3-OS. The major exception is the problem of thermal effects on high resolution optical performance.

6. References
Discussions of solar optical research objectives are given by H. Zirin, Orbital Astronomy Supporting Facility Study, Vol II, Part 1, Appendix C-11(McDonnell Douglas Report DAC-58142, July 1968), and on pp 210-213, 216-217, 224-225, 238-239, 242-245, 248-249, and 268-271 of the same volume. Another major discussion is in the Report of the Solar Space Astronomy Panel, A Long-Range Program in Space Astronomy (Position Paper of the Astronomy Missions Board), NASA Publication SP-213, July 1969, pp 127-176.

The solar telescope referred to above is detailed in the OASF Study, Vol II, McDonnell Douglas Report DAC-58142, July 1968, pp 303-323.

Critical Issues Addressed by Research Cluster

3-SO

OPTICAL STUDIES OF THE SOLAR PHOTOSPHERE AND CHROMOSPHERE

3.1.5.3.1.3.2.1.2.1.2.1.1.1
What is the general magnetic field of the photosphere?

3.1.5.3.1.3.2.1.2.1.2.1.1.2
How does the photosphere vary with time?

3.1.5.3.1.3.2.1.2.1.2.2.3.1
What is the atomic and molecular composition of the photosphere as a function of height?

3.1.5.3.1.3.2.1.2.2.1.1
How does temperature vary radially and heightwise in sunspots?

3.1.5.3.1.3.2.1.2.2.1.2
How does the magnetic field vary radially and heightwise in sunspots?

3.1.5.3.1.3.2.1.2.2.1.3
Are there photospheric lateral currents exerting pressure on sunspots?

3.1.5.3.1.3.2.1.2.2.2.2
What are the sunspot granulation lifetimes?

3.1.5.3.1.3.2.1.2.3.1
What do the interstitial regions of the granulation look like at resolutions better than 0.5-arc-sec?

3.1.5.3.1.3.2.1.2.3.2
Do granule lifetimes vary with the solar cycle?

3.1.5.3.1.2.2.1.2.3.3
Does chemical composition vary from photosphere granule centers to interstitial region centers?

3.1.5.3.1.3.2.1.3.1.2.2.1.1
How does the vertical chromosphere temperature profile vary as a function of latitude and time?

3.1.5.3.1.3.2.1.3.1.2.2.1.2
Are there anomalies or fine structure in the vertical chromosphere temperature profile?

3.1.5.3.1.3.2.1.3.1.2.2.2.1
How does the density profile of the chromosphere vary as a function of latitude and time?

3.1.5.3.1.3.2.1.3.1.2.2.2.2
Are there anomalies or fine structure in the density profile of the chromosphere?

3.1.5.3.1.3.2.1.3.1.2.2.3.1
How does the composition of the chromospheric vary as a function of height, latitude, and time?

3.1.5.3.1.3.2.1.3.1.2.2.4.1
What is the synoptic variation of the chromospheric spectrum throughout the UV and XUV?

3.1.5.3.1.3.2.1.3.2.1
Is there a magnetic field within the spicules?

3.1.5.3.1.3.2.1.3.2.2
What is the structure of any magnetic field in the spicules?

3.1.5.3.1.3.2.1.3.4.1
What is the three-dimensional magnetic field geometry in a flare area before, during, and after a solar flare, to 5 arc-sec resolution?

3.1.5.3.1.3.2.1.3.4.3
What is the UV emission line spectrum of solar flares?

3.1.5.3.1.3.2.1.3.4.4
What is the fine structure of solar flare fibrils?

3.2.5.3.1.3.2.1.1.1.3.1
What is the typical time sequence of the events: flare precursor(s), flare X-ray enhancement, chromosphere emission enhancement, ratio burst?

3.2.5.3.1.3.2.1.1.2.4.3
What are the spectral line profiles as a function of height in the solar atmosphere?

3.2.5.3.1.3.2.1.1.3.1.1
Does a supergranulation pattern exist in the solar exterior?

3.2.5.3.1.3.2.1.1.4.2.1
Why do solar prominences temporarily disappear?

3.2.5.3.1.3.2.1.2.2.1.1
What are the profiles of spectral lines produced in sunspot regions?

3.2.5.3.1.3.2.1.2.3.1.1
What is the apparent (two-dimensional) structure of solar granules?

3.2.5.3.1.3.2.1.2.3.2.1
What is the temperature distribution across granules and intergranular regions?

3.2.5.3.1.3.2.1.3.1.2.3.1
What is the structure of the chromospheric network?

3.2.5.3.1.3.2.1.3.2.1.1
How do the density, temperature, and composition of spicules compare with interstitial regions?

3.2.5.3.1.3.2.1.3.4.2.1
Do flare spectra show lines attributable to nuclear reaction products?

3.2.5.3.1.3.2.1.3.4.4.1
How do the structure, composition, temperature, and energy release of a solar flare compare with surge prominences?

RESEARCH CLUSTER SYNOPSIS—ASTRONOMY

3-XR Precise Location, Size, and Structure of Known Discrete X-Ray Sources, and Existence of Additional Unknown Sources

1. Research Objectives

The general objective of this research area* is to determine the identity of the discrete (nonsolar) x-ray sources; i. e., in terms of optical or radio counterparts, such as supernovae remnants or nebular ejecta, neutron stars (which may or may not all appear as pulsars), peculiar stars or nebulae, galaxies, or quasars. Such identifications of x-ray sources can contribute much to our understanding of their physical properties, some of which are best determined in optical or radio wavelengths. The most obvious of the latter properties are distances, which are vital to the determination of x-ray luminosities. Currently, we have no means of obtaining distances of x-ray sources other than by identification of particular optical counterparts, ** whose distances are derived by techniques peculiar to optical stellar and galactic astronomy.

2. Background and Current Status

Two distinct classes of x-ray source counterparts are known: supernovae ejecta and peculiar bluish stars. The former include the Crab Nebula (Taurus X-1), Cassiopeia A (a strong radio source), SN 1572 (Tycho's supernova), and Vela X-1. Some controversy remains concerning the last three of these. The latter class includes Scorpius X-1 (the strongest x-ray source) and probably Cygnus X-2. A third probable class of x-ray sources (galaxies) is suggested by the proximity of M87 (Virgo A, a strong radio galaxy) to a reported x-ray source. Other possibilities, not yet established, are Wolf-Rayet stars, novae, and planetary nebulae.

The association of some x-ray sources with supernovae ejecta is not particularly instructive, since the actual source could be the nebular ejecta or the stellar remnants. A lunar occultation observation of the Crab Nebula has indicated a finite (i. e., nonstellar) angular subtense of Taurus X-1 (though smaller than the visible extent of the nebula); but more recently the x-ray source has been found to emit pulsed x-radiation with the same period as the pulsar (NP 0532) in the nebula, which is a neutron star. The answer to this seeming contradiction is probably that the neutron star produces the pulsed x-radiation, while a much larger region of the nebula itself produces the steady x-ray component by small-angle scattering or absorption and re-emission of the neutron star radiation. The object Vela X-1 is also now thought to be associated with a pulsar.

---

*Literature surveyed for this synopsis relates mostly to research performed before late 1969.

**Optical counterpart search is included in Research Cluster 3-OS.

The specific nature of the faint bluish stars, which are the counterparts of Scorpius X-1 et al., is not known, but it is not improbable that these are supernovae (or novae) remnants lacking detectable associated nebulosity. Their luminosities in visible wavelengths are of the same order as the Crab Nebula pulsar; consequently, it is indicated more specifically that the counterparts are non-pulsing neutron stars.

The current state of understanding of discrete x-ray sources offers strong motivation to determine their location and angular structure with substantially increased precision. The angular positions of the 50 or more known sources are currently determined to no better than a few arc minutes (min)—excepting Taurus X-1—and some to only 2 deg. These should be improved to 1 to 10 sec, and searches should be conducted for an additional 30 to 50 objects, aiming at a location accuracy of ~ 0.1 deg or better. With an enlarged sample of sources, successful optical identifications should increase. The angular structures of even the strongest sources are presently determined only as upper limits on dimensions, and with a precision of only a few arc minutes. There is an urgent need for ascertaining the structure with 1 to 10-sec resolution, especially for the objects with identified optical counterparts. This would materially clarify the spatial relationship of the sources to the counterparts, e.g., in ambiguous cases such as the Crab discussed above.

3. Description of Research

This research cluster proposes (1) a sky survey to detect new, weak discrete x-ray sources and to locate them to within ~ 0.1-deg accuracy; (2) x-ray imagery of strong sources with ≈ 1-sec angular resolution to determine precise locations and angular structure. The energy range of interest in both cases is 1 to 20 kev (12 to 0.5 Å), and spectral resolution $\Delta\lambda/\lambda \sim 0.1$ to 1 will be adequate. The detection threshold (flux) for the first case should be $\sim 10^{-13}$ erg cm^{-2} sec^{-1}, or 10^3 times <u>smaller</u> than the weakest presently known sources.

The optimum instrument for program (1) appears to be a large-area (at least 100 sq ft) proportional-counter array, which achieves the required angular resolution by modulation collimators within the individual counter modules. The array would scan the sky by virtue of its orbital motion and occasional reaiming to within a few degrees accuracy. An entire sky scan or selected area scan could be completed in 4 to 30 days; therefore, repeat scans to monitor variable sources would be possible. The output of the counters (voltages, proportional to source photon fluxes) would be recorded on magnetic tapes, which could either be played back for direct transmission to Earth or recovered bodily. The second case (2 above) will require a large grazing-incidence x-ray telescope, having a collecting area equivalent to 0.5 m^2 at normal incidence. It would be actively pointed and guided, and would photographically record x-ray images.

Because of its size, the proportional counter array will probably require assembly from modules by men in orbit. Once deployed, however, its operation will be completely automatic. Some maintenance by men may occasionally be required, as well as recovery of magnetic data tapes.

There is no doubt that the large (40-ft-long)x-ray telescope will require assembly and initialization (such as optics alignment and focus tests) by men in orbit, plus periodic maintenance. As with the optical telescopes (Research Cluster Synopses 3-OS, 3-OW, and 3-OB), the best solution to the target-acquisition problem may be real-time monitoring and control by men in a proximate (but detached) station via television.

4. Impact on Spacecraft
The proportional counter array will have almost no impact on a proximate space station, from which it will be detached (though not necessarily remote), including only the common requirement for a technician to perform occasional extravehicular maintenance work. The large x-ray telescope, however, may necessitate inclusion of a control area in the station, where an observer would control and monitor the telescope pointing.

5. Required Supporting Technology Development
The major technical support task is development of efficient methods and devices to exclude stray particulate radiation (Van Allen electrons, solar protons, and cosmic rays) from the x-ray instruments. This is especially crucial for the proportional counter array. Also, a proven target acquisition system adequate to bring an x-ray "point" source into the center of the field of the large grazing-incidence telescope must be developed.

6. References
The chief reference on scientific objectives utilized for this synopsis and for Experiment Group Description 3-XR is A Long-Range Program in Space Astronomy (Position Paper of the Astronomy Missions Board), NASA Publication SP-213, July 1969, pp. 16-45. Also consulted was Orbital Astronomy Support Facility Study, Vol. II, Part 1, Appendix B.

Critical Issues Addressed by Research Cluster

3-XR

PRECISE LOCATION, SIZE, AND STRUCTURE OF KNOWN DISCRETE X-RAY SOURCES, AND EXISTENCE OF ADDITIONAL UNKNOWN SOURCES

3.1.1.1.1.2.1
What are the angular size and structure of discrete-x-ray sources?

3.1.1.1.2.1
What are the spectral energy distributions of discrete x-ray sources?

3.1.1.1.2.1.1
How do discrete x-ray sources vary from source to source?

3.1.1.1.2.1.2
How do discrete x-ray sources vary as a function of time?

3.1.1.1.2.2
What polarizations, if any, exist in discrete x-ray sources?

3.1.1.1.3.1
What are the precise locations of the discrete x-ray sources?

3.1.4.4.2.1
Is there evidence anisotropy or angular variations in the radiation from intergalactic space?

3.1.4.4.2.2
What is the typical temperature of intergalactic diffuse matter?

3.1.4.4.2.3
What is the typical density of intergalactic diffuse matter?

3.1.5.3.1.4.1.1.3
What are the apparent proximities of pulsars to discrete x-ray sources?

3.1.5.3.1.4.1.2.1
What are the pulse periods and period changes of pulsars?

3.1.5.3.1.4.1.2.2
What are the spectral flux distributions of the pulsars as a function of time in pulses and between pulses?

3.2.1.1.2.3.1
What is the fine spectral distribution of the line-emission radiation of x-ray sources?

3.2.1.1.3.1.1
What is the spatial distribution of the discrete x-ray sources?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.		TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK SEQUENCE†
3-XR													
1	A-1	Prepare For Assembly and Deployment In Orbit	Console	3	None		5-B	1	60	1			
	A-2	Inspect and Maintain Equipment	PSA	4	EVA	X	5-B	as req.	6 hr/yr	1			
	A-3	Control Remote Target Acquisition	Console	5	None	X	6-A	1	60	1			
	A-4	Counter Array Remote Re-Aiming	Console	5	None	X	6-A	1	120	1		54 days	
	A-5	Change Photographic Film	PSA	8	EVA	X	19-C	1	180	1			
	A-6	Monitor Telescope to Verify Pointing and Aiming	Console	5	None		6-A	1	300	1			
	A-7	Remove and Replace Magnetic Data Recording Tapes	PSA	8	EVA	X	19-C	1	120	1			
	A-8	Assemble & Deploy	PSA	3	EVA	X	5-B	1	12 hr	1			

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS—ASTRONOMY

3-LF: Location and Properties of Discrete Low-Frequency (LF) Radio Sources, and Structure and Properties of Diffuse Sources

1. Research Objective

The ultimate goal of this research is to determine physical properties, emission and absorption mechanisms, and evolutionary characteristics of low-frequency (10 to 0.1 MHz) radio sources, which are expected to be objects or matter consisting of ionized gases or plasmas. Candidate sources are radio galaxies; quasars; the intergalactic plasma; galactic radio sources, such as pulsars, supernovae remnants, and the nucleus; galactic HII regions; the galactic (electron) corona or halo; and the galactic disc plasma (Reference 1. Solar system sources are not treated in detail here.). This knowledge can contribute significantly to such areas as plasma physics, gravitational theory, cosmic-ray physics, and cosmological theory. The research steps may be broadly described as (1) measurement of the LF radiation; (2) idenfification or discrimination of the source or sources producing the radiation; (3) fitting the measurements to theoretical predictions, which assume specific source properties and emission and absorption mechanisms, thereby verifying (or rejecting) the supposed mechanisms and obtaining source physical data; and (4) comparing results with other relevant observations (ground-based radio, cosmic rays, gamma rays, etc.) to check for consistency, to resolve ambiguities, or perhaps to demonstrate discrepancies.

2. Background and Current Status

The possible LF sources listed above include discrete and diffuse sources, which will be defined here, respectively, by $\alpha < \theta_A$ and $\alpha \geq \theta_A$, where α is the angular subtense of the source and θ_A is a given antenna resolution limit. To date (mid-1970), no discrete sources outside the solar system have been detected, owing to the enormous antenna sizes required to achieve appreciable angular resolution and resulting capability to distinguish discrete source radiation against a substantial background. The earliest rocket- and satellite-borne antennas were electrically short (approximately 20 m long) dipoles with essentially no angular resolution capability, which could therefore measure only the cosmic LF background radiation from the entire sky. Nevertheless, by determining the flux-frequency distribution (which will hereafter be termed the "LF spectrum"), some conclusions could be drawn concerning the dominant emission mechanism; average source electron energy spectra; and limits on electron temperature, density, and magnetic-field strength. More recently the Radio Astronomy Explorer (RAE-1), operating in a 6,000-km-high orbit, obtained background measurements with about a 45-degree angular resolution along the galactic disc and in the directions of the galactic poles, using two opposed 230-m-long V antennas

and receivers sensitive to 0.2- to 10-MHz frequencies, Reference 2). Amont the early results of this mission were effective discrimination at 2.2 and 6 MHz of contributions by the disc plasma and the galactic corona. A second RAE will be placed in lunar orbit in the near future, where it can achieve better angular resolution, using the moon's limb as an occulter. It should provide improved data on the angular distribution of the LF background, detect a number of discrete LF sources, and yield useful spectral data for some of the stronger ones.

3. Description of Research

The present research cluster involves a major improvement in observational capability beyond the above missions. It is proposed that a very large (though relatively light weight) LF antenna system be erected in Earth orbit and used to scan the sky continuously at 10 to 20 fixed frequencies in the range of 10 to 0.1 MHz. The specific apparatus chosen is termed the Kilometer Wave Orbiting Telescope (KWOT), which is basically a thin-wire rhombic antenna with 5-km-long legs and two coupled 3-element (end-to-end) short-dipole arrays mounted parallel to, but outside, the minor diagonal of the rhombus. The rhombic antenna's reception beam cross-section will be a 6- by 16-degree ellipse centered in the antenna plane (the larger beam dimension being perpendicular to this plane), corresponding to an 80-square-degree reception solid angle. Angular resolution of 1.7 degrees will be achieved, however, by electrically combining the outputs of the rhombic and dipole array systems, which constitute an interferometer (Reference 3). The KWOT should be able to detect and measure the LF spectra of dozens (perhaps hundreds) of discrete sources and provide detailed maps of the celestial distribution of the diffuse background of the frequencies mentioned.

The requirement to observe frequencies as low as 0.1 MHz (plus structural stability considerations) means that the KWOT must be located in a very high orbit: synchronous orbit (19,300 nmi) or higher. The nominal design calls for fully automatic deployment, with the role of man limited to occasional servicing. Manned participation in the deployment has been considered, however, and remains somewhat controversial. Factors that enter this consideration obviously include a proven low- to high-orbit transfer capability and a well-developed EVA capability.

4. Impact on Spacecraft

As presently conceived, the antenna system would be launched as a rather compact package, and following orbit insertion and separation from the launch vehicle, it would be reeled out to proper configuration by firing thruster rockets mounted on each of four subsatellites, which will finally assume positions at the acute apices of the rhombus and the outer ends of the dipole arrays, respectively. The initial thruster firing would both separate the subsatellites from the central structure (called the central observatory), and impart a rotation to the system.

Centrifugal force would then effect the rest of the antenna erection. Once in proper shape, maintained actively by control thrusters as well as by centrifugal force, the antenna system would be put into a slow precession mode (0.5 degrees/hr), which together with the spin rate of 6 degrees per minute would cause it to scan the entire sky in 15 days. With all subsystems operational, the astronomical measurements could commence. Antenna system and measurement control would be on remote command from Earth via a communication link and online computer located in the central observatory, also housing data storage and processing units plus a long-range telemetry transmitter. Since optimum performance of the antenna system requires varying the rhombic minor diagonal with the frequency of the measurement, a large number (10 to 20) of sky scans are needed to cover the 0.1- to 10-MHz range. A few repeat scans at fixed frequencies are also desirable to search for, and perhaps monitor, variable LF sources. The total mission time, therefore, would be at least 1 year, and probably 2 years.

5. Required Supporting Technology Development

The major problems associated with the KWOT involve the strength-diameter-conductivity relations of candidate antenna wire materials. The nominal deployment scheme requires further study, especially regarding accurate monitoring of the subsatellite configuration evolution and possibly useful roles for man.

6. References

1. A Long-Range Program in Space Astronomy (Position Paper of the Astronomy Mission Board), NASA Publication SP-213, July 1969, pp. 102-126.

2. R. G. Stone. Research Results from the Radio Astronomy Explorer, AIAA Paper No. 69-1049, 1969.

3. The KWOT is described in some detail in the Orbital Astronomy Support Facility Study, Vol. II, Book 1, June 1968, pp. 85-108, which also gives references to the original design studies.

Critical Issues Addressed by Research Cluster

3-LF

LOCATION AND PROPERTIES OF DISCRETE LF RADIO SOURCES, AND STRUCTURE AND PROPERTIES OF DIFFUSE SOURCES

3.1.1.6.1
What presently unknown types of astronomical sources or objects exist?

3.1.4.3.1.2.1
What are the spectral flux distributions and luminosities of the quasars?

3.1.4.3.1.2.1.1
How do the quasars vary with time?

3.1.4.3.1.2.1.2
How do the quasars vary from source to source?

3.1.4.3.1.2.2
What are the polarizations of quasar radiation? Are there variations with wavelength and time?

3.1.4.4.2.1
Is there evidence for anisotropy or angular variations in the radiation from intergalactic space?

3.1.4.4.2.2
What is the typical temperature of intergalactic diffuse matter?

3.1.4.4.2.3
What is the typical density of intergalactic diffuse matter?

3.1.5.1.1.5
What is the structure of the galactic nucleus?

3.1.5.1.1.9
What is the structure of the galactic 'hat brim'?

3.1.5.1.1.10
Are there not-as-yet classified or unknown large-scale structures in the Galaxy?

3.1.5.1.1.12
What is the structure of the galactic corona?

3.1.5.3.1.3.2.1.1.1.1
What paths do flare- and surge-generated particles take in traversing the solar atmosphere?

3.1.5.3.1.3.2.1.3.1.1.1
Are there precursor waves traveling from solar flare centers to later-flaring elements of major flares?

3.1.5.3.1.3.2.1.4.1.1.1
What are the three-dimensional trajectories of the sources of Type IV radio bursts?

3.1.5.3.1.3.2.1.4.1.2.1.3.1.1
Does the solar wind have its origin in heliographically restricted, rather than being a (modified) general coronal expansion?

3.1.5.3.1.4.1.2.2
What are the spectral flux distributions of the pulsars as a function of time in pulses and between pulses?

3.1.5.4.1.1.1.2.1
What are the mass, size, and structure of bright nebulae?

3.1.5.4.1.1.1.2.2
What are the temperature and composition of bright nebulae?

3.1.5.4.1.1.2.1.1
What is the smoothed spatial density distribution of interstellar gas in the Galaxy and in other galaxies?

3.1.5.4.1.1.2.2.1
What are improved electron temperatures and densities in HII regions?

3.1.5.4.1.1.2.2.2
What are the temperatures of HII regions?

3.1.5.4.1.1.2.2.6
What are the characteristic sizes and masses of large interstellar gas clouds in the Galaxy?

3.1.5.4.1.1.2.2.7
What are the temperatures of large interstellar clouds in the Galaxy?

3.1.5.4.1.2.1.2
What is the structure of the interplanetary plasma?

3.1.5.4.2.1.1.1
What is the typical magnetic field strength in the interstellar medium, and are there large deviations from the average?

3.2.2.2.2.3
Do clouds of intergalactic matter exist inside or outside clusters of galaxies?

3.2.2.2.2.4
What are the densities, sizes, and total mass of any clouds of intergalactic matter?

3.2.4.3.1.1.1.5
What are the temperature and composition of quasars?

3.2.4.4.2.2.3
What are the density, temperature, and composition of bridges, filaments, etc., apparently connecting certain galaxies?

3.2.5.1.1.3.2
What is the electron density variation with z at moderate and large distances from the galactic plane?

3.2.5.2.2.1.4.2
Does the correlation of Jupiter's decametric radio emission with the motion of Io occur at lower frequencies?

3.2.5.3.1.3.2.1.1.1.3.1
What is the typical time sequence of the solar events: flare precursor(s), flare x-ray enhancement, chromospheric emission enhancement, radio burst?

3.2.5.3.1.3.2.1.1.1.4.1
What energy release is associated with each type of active event in the coronal heating mechanisms?

RESEARCH CLUSTER
NO. 3-LF

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLU-SIVE‡	CREW SKILL†	NO. REQUIRED	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURA-TION†	TASK CONCURRENCY†
3-LF												
A-1	Checkout Satellite System	Console	3	None		5-B	1	2 hr	1			
A-2	Prepare Deployment	Console	3	None		5-B	1	1 hr	1			
A-3	Switch Power to Satellite	Console	3	None	X	5-B	1	1/2 hr	1			
A-4	Separate From S/C	Console	2	None	X	5-B	1	1/2 hr	1			
A-5	Monitor Deployment	Optical	2	None	X	6-B	1	1/2 hr	1			
A-6	Inspect Periodically	Optical	5	None	X	6-B		2 hr	1			
A-7	Activate Deployment	Console/PSA	2	Potential EVA	X	5-B	1	1/2 hr (Advanced EVA techniques are required for profitable application of man in support of experiment)	1			
A-8	Calibrate Antenna	Console	4	None	X	6-B	1	2 hr	1			
A-9	Initiate Spin Mode	Console	2	None	X	5-B	1	1/2 hr	1			
A-10	Check Subsystems Status	Console	4	None		5-B	1	2 hr	1			
A-11	Service Periodically If Required	PSA	4	EVA	X	5-B	1	2 hr	1			

†See Legend of Codes, next page. ‡ X(or other entry) indicates that time of crew member(s) cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

Appendix D

AREAS OF ASTRONOMY REQUIRING ADVANCED STUDY

INFRARED ORBITAL ASTRONOMY

No manned orbital (purely) infrared research clusters are derived in the present study. This position reflects an evident lack of urgency for orbital programs in this area on the part of some of the foremost researchers in the discipline. If detector-preamplifier combinations continue to be improved at the current rate, substantial advances in infrared observational performance will be possible using (1) uncooled airborne and balloon-borne 1-m telescopes and (2) uncooled satellite telescopes with apertures in the 0.3- to 1-m range[1]. The latter would be logical candidates for an OAO-class (unmanned) mission. It is concluded, therefore, in accord with the Infrared Space Astronomy Panel of the Astronomy Missions Board (1969), that detailed consideration of a 1-m (or larger) optimized infrared space telescope for the 1970's would be premature.

If IR sensor development reaches a plateau during the near future, then observations using orbiting telescopes would become desirable. The most suitable telescope for this work would have gold-coated optics and would be totally cooled to very low temperatures. One proposed design[2] has a 1-m aperture f/10 Ritchey-Chretien optics (primary f = 1.5), yielding 1-arc-sec angular resolution at a 4-micron (μ) wavelength throughout a 5-arc-min diameter field of view. As in the case of the optical telescopes described in the Research Cluster Descriptions 3-OW, 3-OS, and 3-OB, a two- or three-fold larger field of view would provide greater observational versatility (which would particularly aid survey work) at the cost of substantial but tolerable deterioration in off-axis image quality. The telescope is intended for observations in the 0.7- to 1000-μ region and would have gold-coated optical surfaces for maximum overall reflectivity in this range of the spectrum. It would be provided with an advanced, state-of-the-art cryogenically cooled (1.5 K) radiometer, a two-dimensional detector array (both with filters for broadband spectral resolution), and an efficient interferometer spectrometer. Observations made possible by the use of these auxiliary instruments include surveys to detect weak infrared discrete sources; radiometry of a variety of known discrete sources with improved photometric precision at wavelengths not previously available, and in some cases with improved angular resolution; the monitoring of selected sources for infrared variability; and high-resolution spectrometry of a number of strong sources.

A key feature of the infrared telescope is its Earth and sun thermal radiation shield, which passively cools the telescope to satisfactorily low temperatures. The shield thermal analysis (Orbital Astronomy Support Facility (OASF) Study, Appendix A) indicates that with a shield of only two layers, the inner face of the second layer would have an equilibrium temperature of 33°K. The proposed shield has five layers of decreasing area, the largest (Earth-facing) measuring 9.6 by 8.15 m in projected area. The shields are not flat; the Earth-facing section has a pronounced sump for better telescope isolation. The telescope is mounted in a two-axis gimbal large enough to permit 120-degree (outer) and 180-degree (inner) slewing with respect to the (projected) shield faces. The astronomical source acquisition and guidance system consists of an auxiliary viewfinder, which taps visible light from the main optics by means of a beam-splitter and images it on a TV camera, plus control moment gyros (which additionally maintain the proper shield orientation). The acquisition of sources would be man-controlled with the aid of the TV monitor; men would also assemble the telescope and shield system in orbit and perform maintenance. Guidance on the selected sources and all astronomical data-taking would be automatic. The chief drawback of the nominal design is that the instrument must be placed in a sun-synchronous (near-polar) orbit for the shield to be effective.

MILLIMETER-WAVE ASTRONOMY

The need to perform millimeter-wave astronomical observations from Earth orbit is difficult to assess. The subject has a rather limited research literature in spite of current interest in the cosmic microwave background and additional interest in planetary emission. The area was not treated by The Astronomy Missions Board nor was it represented in the instruments derived in the OASF Study.

Atmospheric attenuation in the 1- to 10-mm wavelength range is due chiefly to water vapor, which mainly produces three absorption bands at 1.4 to 1.8, 2.4 to 3.0, and 3.4 to 8 mm. The attenuation is not total in these bands, however, for at a dry mountain observatory site, it is more than 50 percent only in the 2.4- to 2.7- and 4- to 6.5-mm ranges, i.e., in only 28 percent of the millimeter-wave range. On this basis, the case for Earth-orbital millimeter-wave astronomy is weak. Moreover, small instruments suitable for measurement of diffuse millimeter-wave radiations are now being launched on sounding rockets to altitudes at which absorption resulting from water vapor is essentially zero. Against these negative arguments, one can only speculate that there might be important phenomena most conspicuous in those wavelengths not transmitted well to the ground, e.g., radiation from discrete sources, which would also escape detection by present rocket-borne instruments. In order to observe any such sources, however, a large (>30-ft diameter) precision paraboloidal antenna would have to be employed, and its assembly in Earth

orbit would probably be an order of magnitude more difficult than the other major instruments considered here. Accordingly, no millimeter wave research clusters have been derived for the period to which this study applies. It is the judgement of the study team, however, that the subject of millimeter-wave orbital astronomy deserves more study by experts than it has received in the past. [3]

OPTICAL SKY SURVEYS

Although the research cluster 3-OS includes the term "optical surveys" in its descriptive title, it is recognized that the telescopes associated with this cluster are not optimized as wide-field survey instruments. Inasmuch as all the optical telescopes discussed in the research clusters have threshold stellar magnitude capabilities well beyond existing ground-based telescopes, it is appropriate to consider whether some of the faint-threshold observations in clusters 3-OS and 3-OW should be preceded by wide-field, or even all-sky, surveys to some magnitude limit beyond approximately $m_V = +21$ (Palomar 48-in. Schmidt camera) which represents the best present surveys.

It is believed that there is no question as to the value of UV stellar surveys to moderately faint magnitude limits. The subject is discussed for example, in a recent review paper by Henize. [4] A program similar to Henize's proposed imagery survey is sketched in the OASF Study. [5]

In the case of visible-wavelength multicolor imagery surveys to extremely faint magnitude limits, however, the need for the data to plan subsequent observations with large, narrow-field, diffraction-limited telescopes is controversial. Moreover, it is rather academic at this time, because existing survey-type telescopes are not well suited to such observations.

In the OASF Study[6] it was shown that a conventional Schmidt telescope, because of its short focal ratio (typically f/3), cannot attain visible magnitude limits much fainter in space than on the ground. More recent calculations by the study team demonstrate further that off-axis optical aberrations--small as they are for Schmidt systems--will cause a substantial deterioration of the limiting magnitude in the outer half of the field. Based on these calculations, the OASF Study results--which suggested that a suitable compromise might be a Schmidt system of moderate focal ratio, e.g., f/10, with a field of view reduced to about 2° --now appear to have been too optimistic.

In view of the clear need for design of an optimum optical survey telescope, it is somewhat premature to propose detailed survey observation programs, so this was not pursued in the present study. There is also a serious problem with the imaging medium,

since glass plates for large survey instruments are too large and heavy to be practical. Film may be usable and, if not too bulky, might be amenable to automatic loading and cycling.

OPTICAL ASTROMETRY

Optical astrometry--the precise determination of angular positions on the celestial sphere--was investigated late in the OASF Study with regard to possible advantages of performing such measurements using data obtained from Earth-orbiting telescopes. Unfortunately, it was not possible to incorporate a discussion of this subject in that study's final report, so the results will be summarized here.

There appears to be a certain amount of misunderstanding about the capability of large-aperture diffraction-limited telescopes to provide great improvements in astrometry. In fact, the significant sources of relative error in the determination of stellar angular positions are[7]:

A. Optical system and photographic plate misalignment.

B. Poor focus, including variation with temperature.

C. Off-axis optical aberrations, especially coma.

D. Spectral energy distribution of the star observed.

E. Atmospheric dispersion (wavelength variation of the index of refraction).

F. Plate measurement accuracy.

Of the above error sources, only the atmospheric dispersion effect would be eliminated by observing from orbit. Note that atmospheric turbulence is not a significant source of error. So long as the telescope produces a symmetric (i.e., circular) star image on the photographic plate, the center of the image can be determined with precision far exceeding the net angular resolution, which includes "seeing" enlargement. Only when the atmosphere is so turbulent that the star's "seeing disc" is fragmented or asymmetric does this affect the quality of observations, and such conditions are rare at good observatory sites. Therefore, a major capability of Earth-orbiting telescopes--diffraction-limited angular resolution--turns out to be of little benefit to astrometric observations.

The two major applications of astrometry are determination of stellar trigonometric parallaxes and proper motions. In both cases, absolute (rather than relative) angular positions are required, and often the systematic accuracy of the reference system is less than the plate measurement (i.e., relative

position) accuracy, or even unknown. It has recently been proposed,[8] for example, that stellar positional displacements resulting from the sun's gravitational field may produce a significant systematic error in parallax determinations, an error heretofore neglected. The systematic (i.e., absolute) accuracy of proper motions is so much in doubt that major observation programs were instituted years ago. Those programs were aimed at establishing a reference system based on selected external galaxies (which presumably have no significant proper motions) rather than on stars in the Galaxy. Orbiting telescopes can apparently do little to advance such work, which involves noninstrumental problems. However, further study of the systematic accuracy aspect of astrometry in connection with Earth-orbital observations appears to be warranted, specifically addressing the possibilities that:

A. The superior detection threshold of orbiting diffraction-limited telescopes may permit the use of very small (presumably very distant) galaxies as reference objects rather than the extended (and rarely circular) galaxies which ground-based programs must utilize.

B. At magnitudes $m_V > 24$, quasars may be numerous enough to serve as practical reference points.

Until such an additional study is undertaken, it would at best be premature to consider seriously astrometric programs using large orbital telescopes. Furthermore, if such studies were to yield favorable results, one would next face the practical observational requirement of extremely long observation periods for proper motion work--at least 20 years between the first and second epoch photographs.

Short of the invention of some novel observing technique, the only sound approach to substantial improvements in the direct determination of stellar distances is the increase of the measurement baseline. For a given probable error in the parallax of a star, it can be shown that the probable error in the distance is inversely proportional to the baseline length. It is the size of the latter error for a 2 AU baseline, rather than the parallax value itself, that limits the reliable determination of stellar distances to $\gtrsim 30$ parsecs.

The practical problems of increasing the measurement baseline by a significant amount--say to 10 AU--are obvious. Even if such a facility could be established, an observatory on one of Jupiter's satellites, for example, would require years to obtain a single series of parallax photographs (2 exposures, 1 parallax determination per star) and a human lifetime to accumulate a

statistically significant set (say 10 series). A site on a high-eccentricity asteroid with a 10 AU major axis (if one could be found) would be no better in terms of required observation time, though it might be easier to reach at times than Jupiter. The only observationally practical platform would be an artificial station with propulsive capabilities far better than current systems.

REFERENCES

1. A Long-Range Program in Space Astronomy (Position Paper of The Astronomy Missions Board). Report of the Infrared Astronomy Panel, NASA Publication SP-213, pp 88-89, July 1969.

2. Orbital Astronomy Support Facility Study. McDonnell Douglas Astronautics Company, DAC-58143, Vol. III, Book 1, pp 109-126, June 1968.

3. Additional discussion of the points presented here will be found in the Orbital Astronomy Support Facility Study. McDonnell Douglas Astronautics Company, DAC-58142, Vol. II, Part 1, pp 48-49, June 1968.

4. K. G. Henize. Optical Telescope Technology Proceedings, NASA SP-233, pp 17-24, 1970.

5. Orbital Astronomony Support Facility Study. McDonnell Douglas Astronautics Company, DAC-58142, Vol. II, Part 1, pp 252-253, June 1968.

6. Orbital Astronomy Support Facility Study. McDonnell Douglas Astronautics Company, DAC-58142, Vol. II, Part 2, pp 140-143, June 1968.

7. P. Van de Kamp. Astronomical Techniques (Stars and Stellar Systems). Vol. II. ed. W. A. Hiltner (Chicago: Univ. of Chicago Press), p 487, 1962.

8. L. Ya. Arifov and R. K. Kadyev. Soviet Astronomy A. J. Vol. 12, p 882, 1969.

APPENDIX A

ORGANIZED OVERVIEW CHARTS

SPACE PHYSICS

A-4-1

Chart 4-1. Organized Overview for Space Physics

- **4.0 SPACE PHYSICS**
  Objective: To explore the space environment to understand its nature and the physical processes that shape it, and to increase man's knowledge of the fundamental laws and principles of physics.
  - **4.1 PHYSICS EXPERIMENTS UTILIZING SPACE**
    What measurements or experiments can be conducted in physics to take advantage of the unique characteristics of the space environment?
    - **4.1.1** In classical mechanics, relativity, and gravitation? (SEE CHART 4-2
    - **4.1.2** In electromagnetism? (Including optics)? (SEE CHART 4-4)
    - **4.1.3** In heat, thermodynamics, and statistical mechanics? (SEE CHART 4-5)
    - **4.1.4** In deformable bodies? (SEE CHART 4-7)
    - **4.1.5** In atomistic structure of matter?
      - **4.1.5.1** In atomic and molecula› physics? (SEE CHART 4-9)
      - **4.1.5.2** In nuclear physics? (SEE CHART 4-10)
      - **4.1.5.3** In high-energy particle physics? (SEE CHART 4-11)
      - **4.1.5.4** In solid-state physics? (SEE CHART 4-12)
      - **4.1.5.5** On interaction of radiation with matter? (SEE CHART 4-11)
    - **4.1.6** In plasma physics? (SEE CHART 4-13)
  - **4.2 PHYSICS OF THE SPACE ENVIRONMENT**
    What are the present state and principles of order and change that describe the space environment?
    - **4.2.1 DIRECT SENSING OF LOCAL SPACE ENVIRONMENT**
      What are the present state and principles of order and change that describe that portion of the local space environment that accessible to direct sensing? (SEE CHART 4-14)
    - **4.2.2 INTERPRETATION OF REMOTE ENVIRONMENT THROUGH LOCAL EXPERIMENTS**
      What local measurements or experiments can be performed in space that will aid in the interpretation of observations of remote sources? (NO CRITICAL ISSUES DERIVED)
    - **4.2.3 REMOTE SENSING OF SPACE ENVIRONMENT**
      What measurements of the space environment can be performed in space utilization remote, sensing techniques (space astronomy)?
  - **4.3 SPACECRAFT ENVIRONMENTAL CONDITIONS**
    What measurements or experiments can be performed to best describe the physics of the spacecraft environmental conditions?
    - **4.3.1** Pollution in the spacecraft environment?
      - **4.3.1.1** Spacecraft surface effects (CRITICAL ISSUES IN TABLE 4)
      - **4.3.1.2** Spacecraft spatial environment (CRITICAL ISSUES IN TABLE 4)
    - **4.3.2** Spacecraft in the natural environment? (CRITICAL ISSUES IN TABLE 4)

Chart 4-2. Space Physics – Classical Mechanics Relativity, and Gravitation

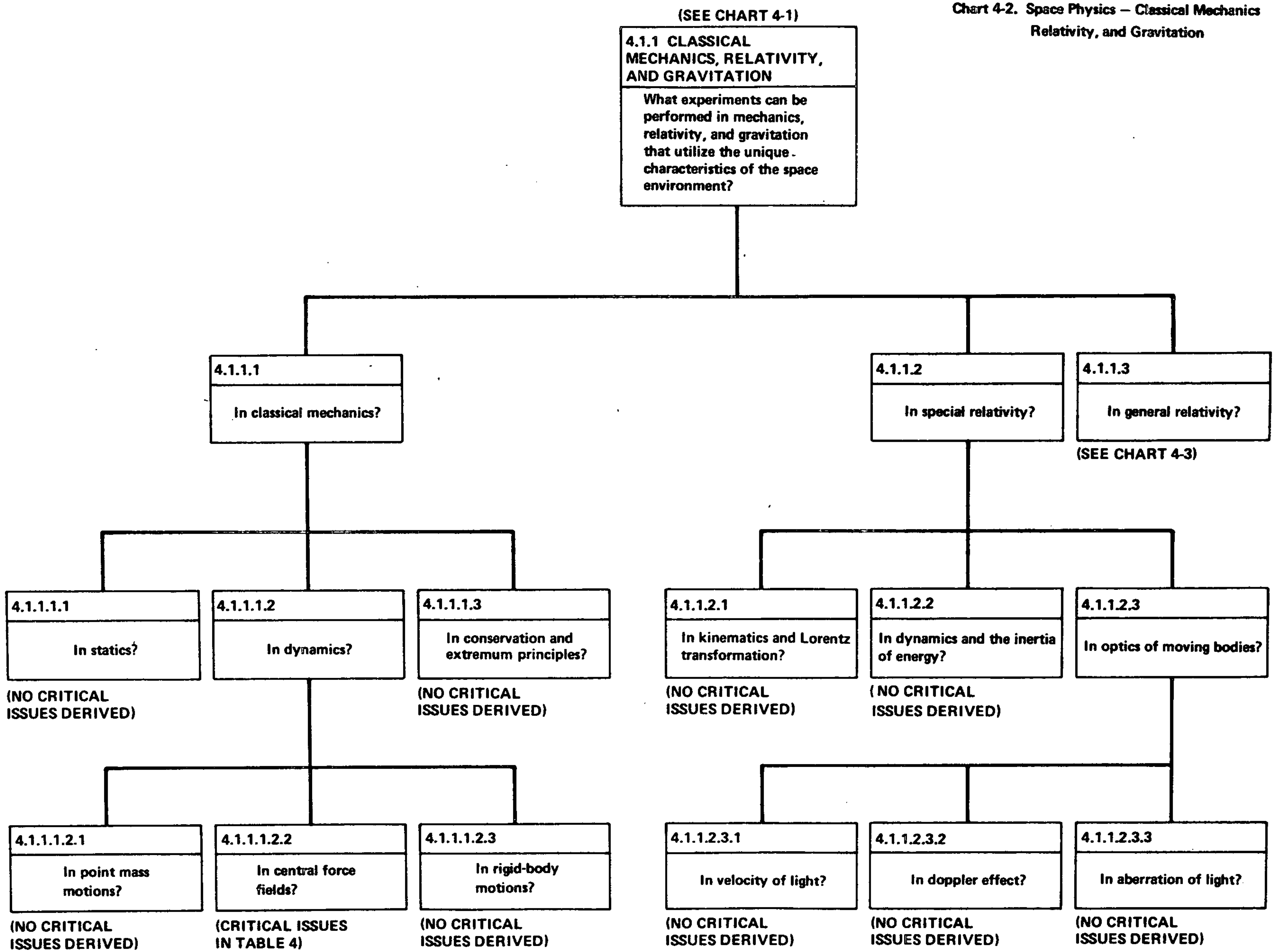


Chart 4-3. Space Physics – General Relativity

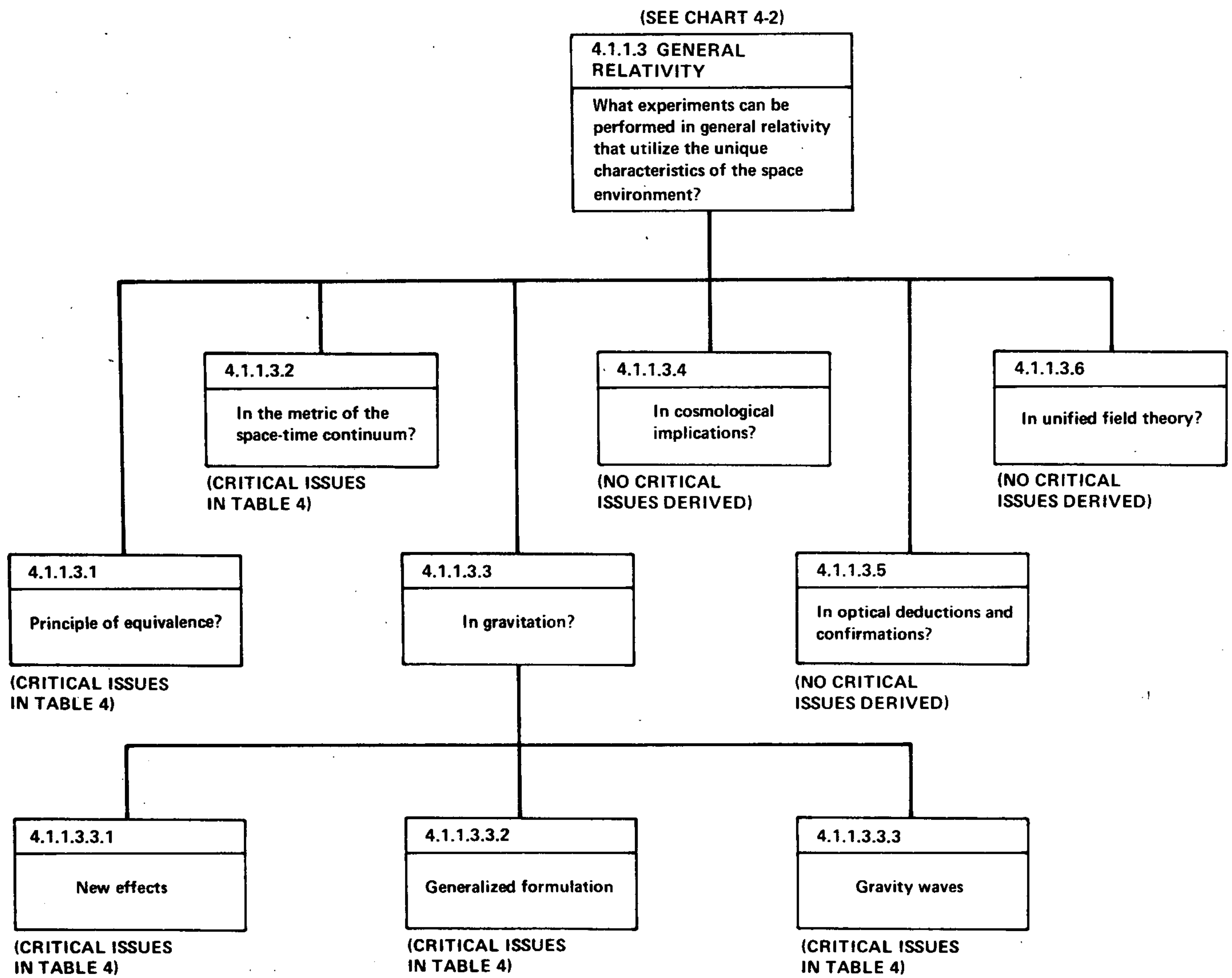


Chart 4-4. Space Physics – Electromagnetism (Including Optics)

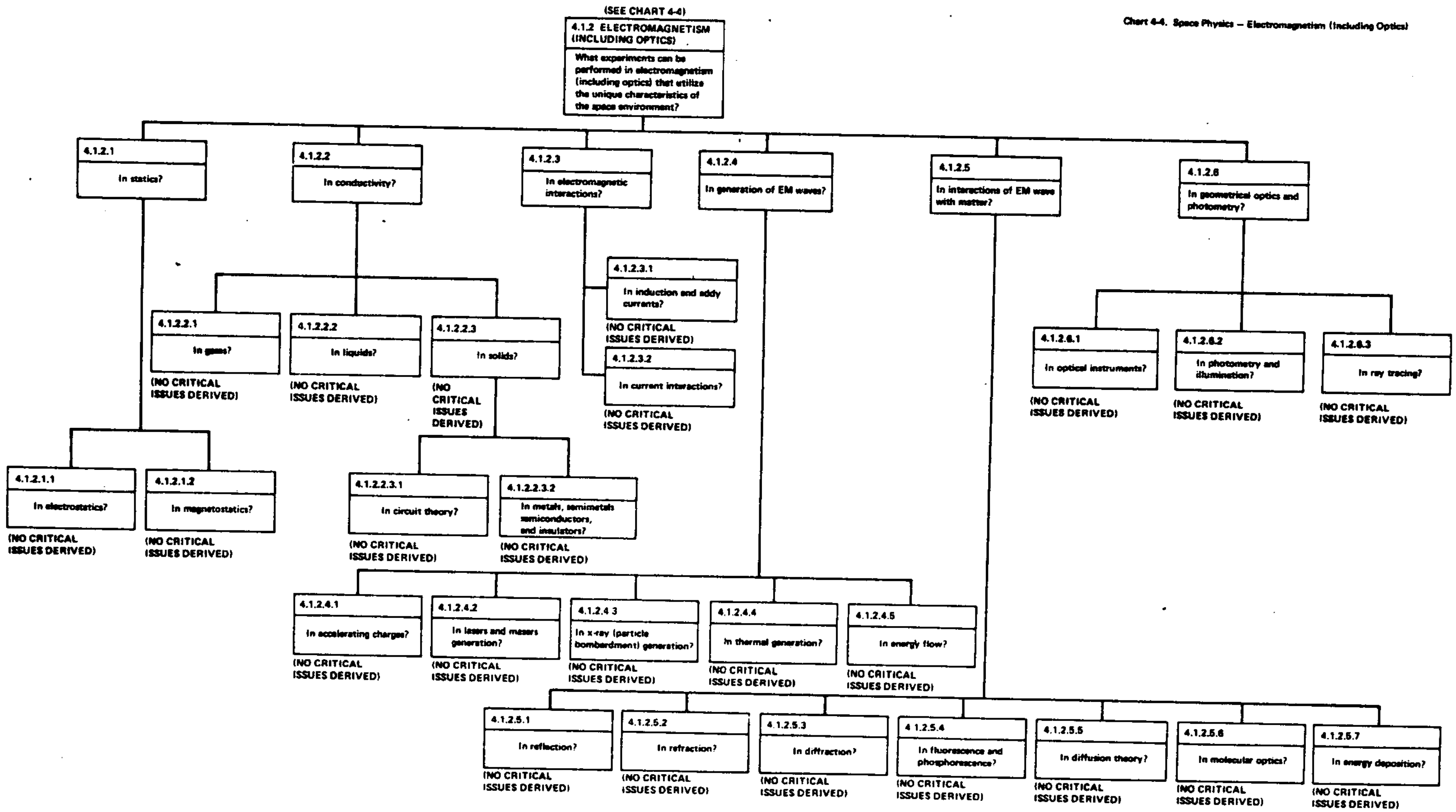


Chart 4-5. Space Physics – Heat, Thermodynamics, and Statistical Mechanics

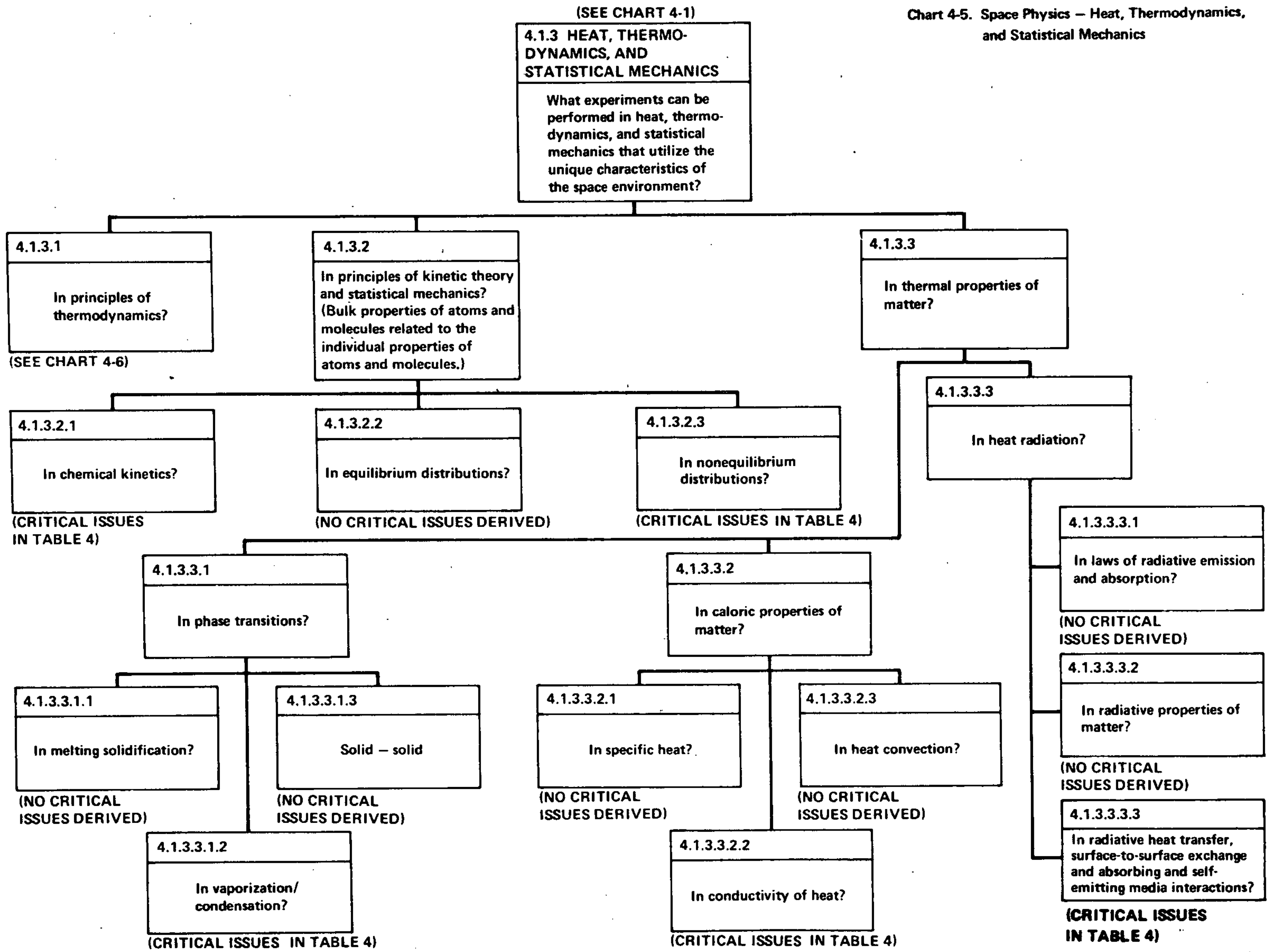


Chart 4-6. Space Physics – Principles of Thermodynamics

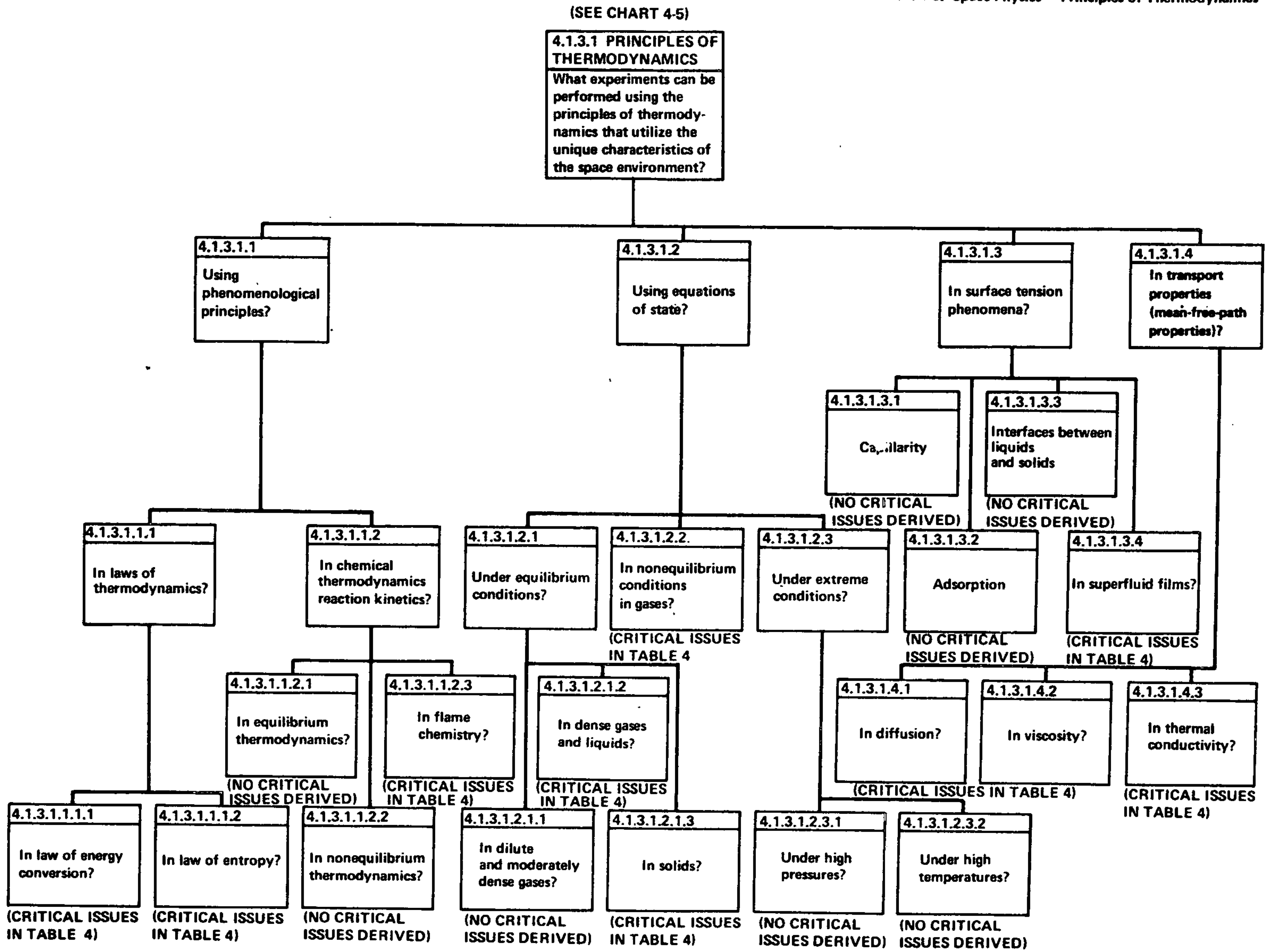


Chart 4-7. Space Physics — Deformable Bodies

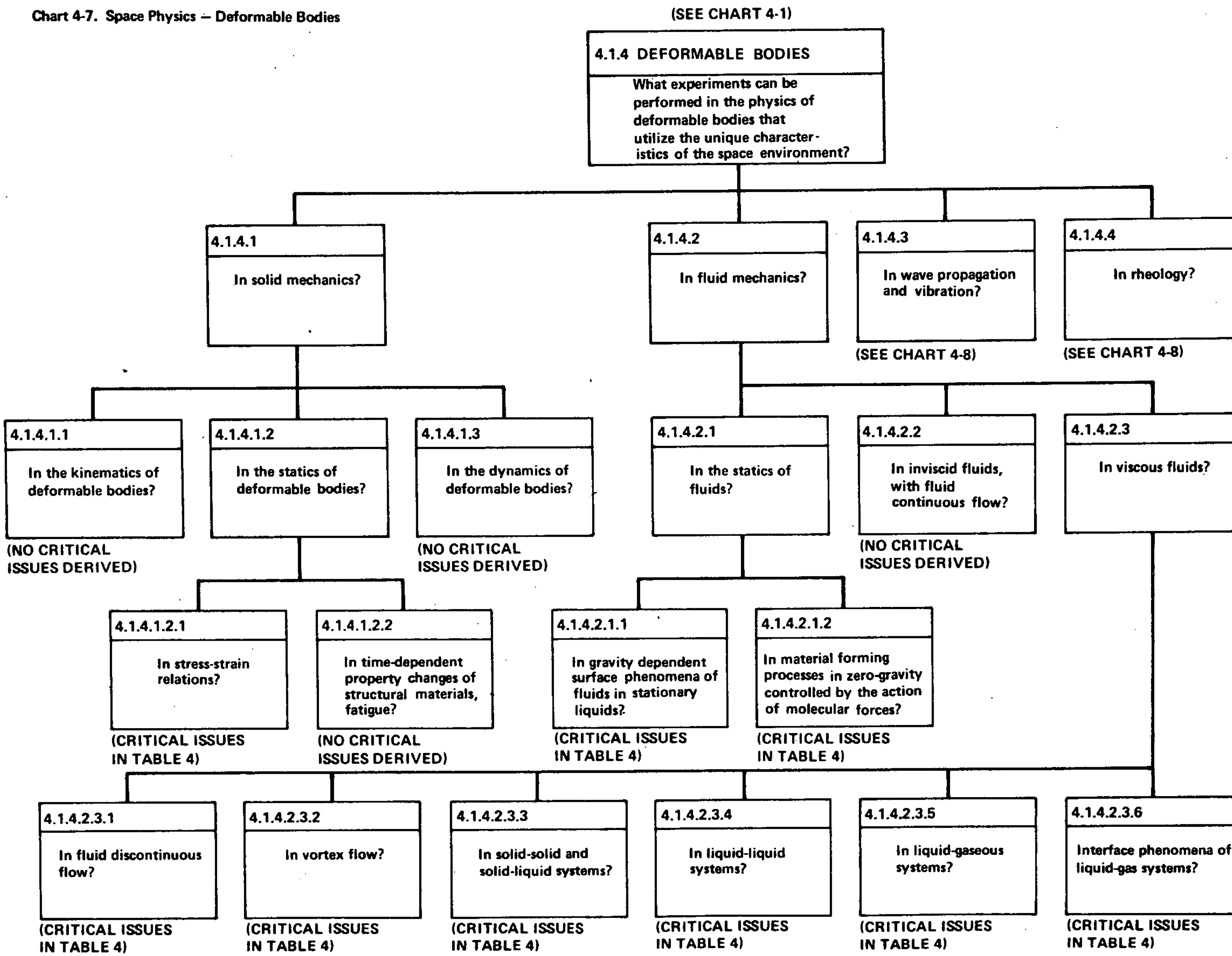


Chart 4-7

Chart 4-8. Space Physics – Wave Propagation and Rheology

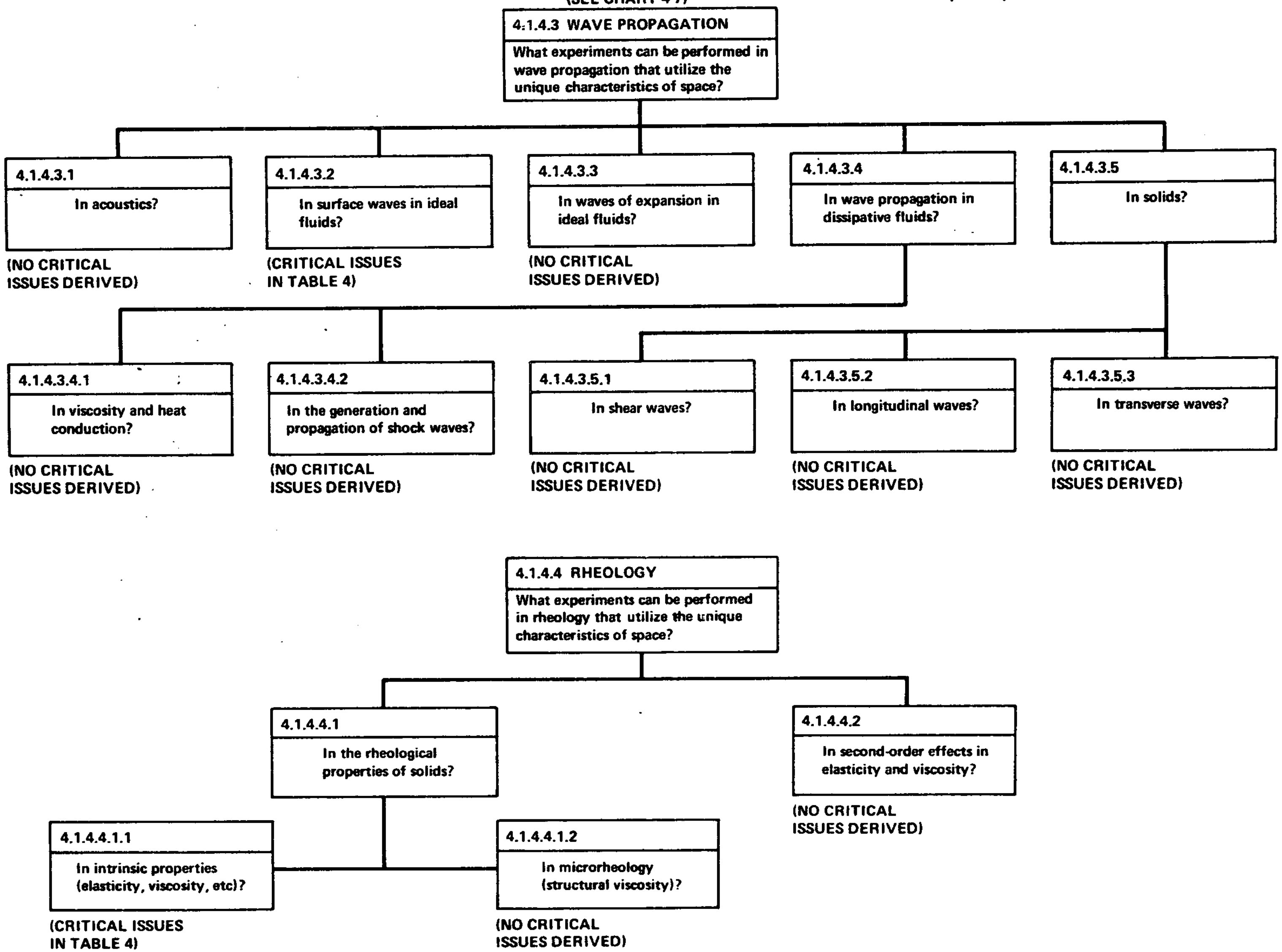


Chart 4-9. Space Physics – Atomic and Molecular Physics

(SEE CHART 4-1)

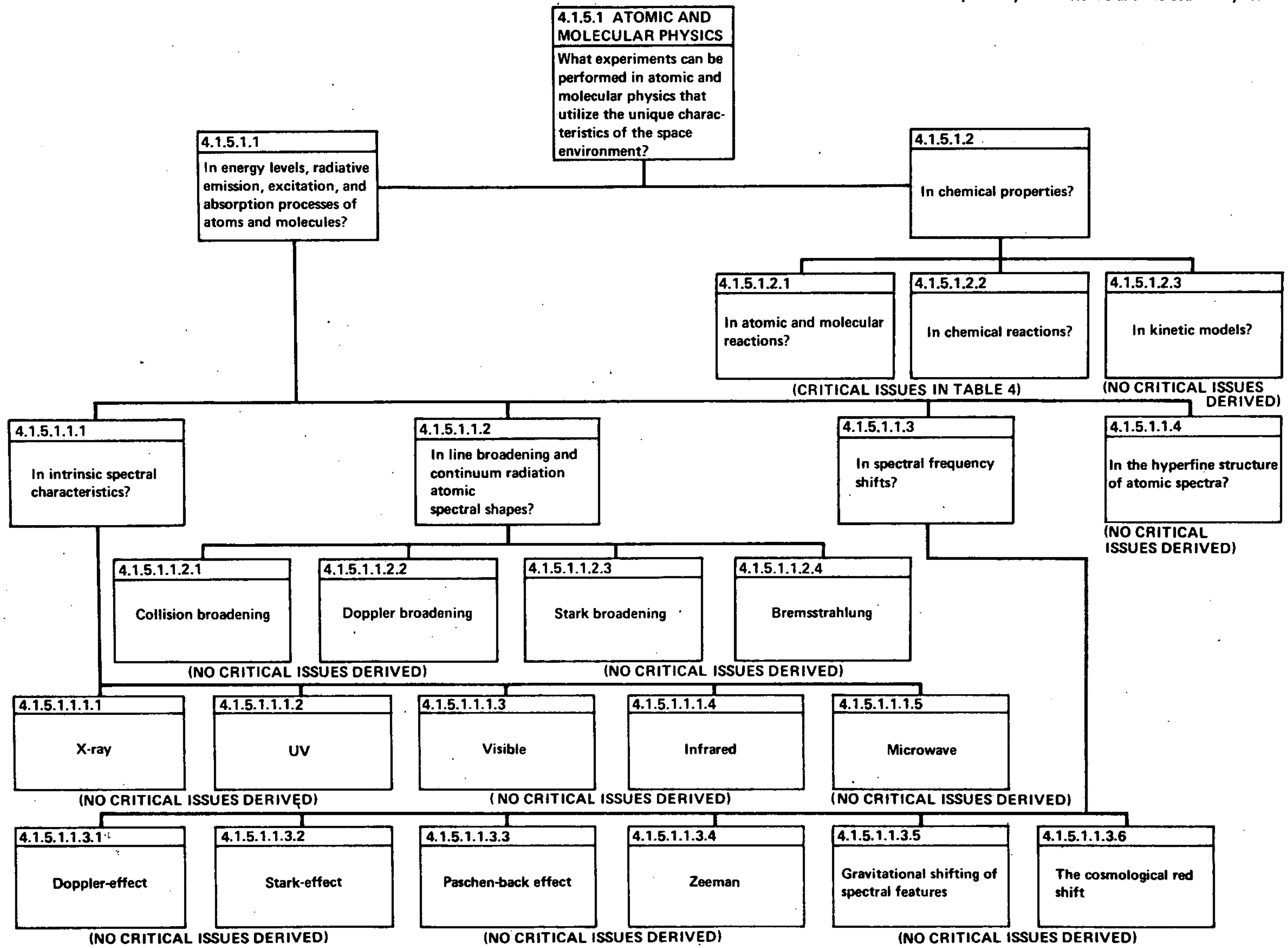


Chart 4-10. Space Physics – Nuclear Physics

(SEE CHART 4-1)

4.1.5.2 NUCLEAR PHYSICS
What experiments in nuclear physics can be performed that utilize the unique characteristics of the space environment?

- **4.1.5.2.1** In nuclear systematics?
  - **4.1.5.2.1.1** Binding energy and stability of nuclei — (NO CRITICAL ISSUES DERIVED)
  - **4.1.5.2.1.2** Masses and radii of nuclei — (NO CRITICAL ISSUES DERIVED)
  - **4.1.5.2.1.3** Angular momentum and moments of nuclei — (NO CRITICAL ISSUES DERIVED)
  - **4.1.5.2.1.4** Isotopic abundance — (NO CRITICAL ISSUES DERIVED)
- **4.1.5.2.2** In nuclear models?
  - **4.1.5.2.2.1** Uniform models — (NO CRITICAL ISSUES DERIVED)
  - **4.1.5.2.2.2** Independent particle model — (NO CRITICAL ISSUES DERIVED)
  - **4.1.5.2.2.3** Many particle models — (NO CRITICAL ISSUES DERIVED)
- **4.1.5.2.3** In nuclear reactions?
  - **4.1.5.2.3.1** Surface collisions — (NO CRITICAL ISSUES DERIVED)
  - **4.1.5.2.3.2** Close collisions — (NO CRITICAL ISSUES DERIVED)
  - **4.1.5.2.3.3** Neutron physics — (NO CRITICAL ISSUES DERIVED)
- **4.1.5.2.4** In nuclear decay?
  - **4.1.5.2.4.1** α – decay — (NO CRITICAL ISSUES DERIVED)
  - **4.1.5.2.4.2** β – decay — (NO CRITICAL ISSUES DERIVED)
  - **4.1.5.2.4.3** Radiative decay — (NO CRITICAL ISSUES DERIVED)
  - **4.1.5.2.4.4** Fission and neutron emission — (CRITICAL ISSUES IN TABLE 4)
- **4.1.5.2.5** With low-energy accelerators?
  - **4.1.5.2.5.1** Cockroft Walton generator — (NO CRITICAL ISSUES DERIVED)
  - **4.1.5.2.5.2** Van de Graaff generator — (NO CRITICAL ISSUES DERIVED)
  - **4.1.5.2.5.3** Linear accelerators — (CRITICAL ISSUES IN TABLE 4)
  - **4.1.5.2.5.4** Cyclotron — (NO CRITICAL ISSUES DERIVED)

Chart 4-11. Space Physics – High-Energy Particle Physics and Interaction of Radiation with Matter

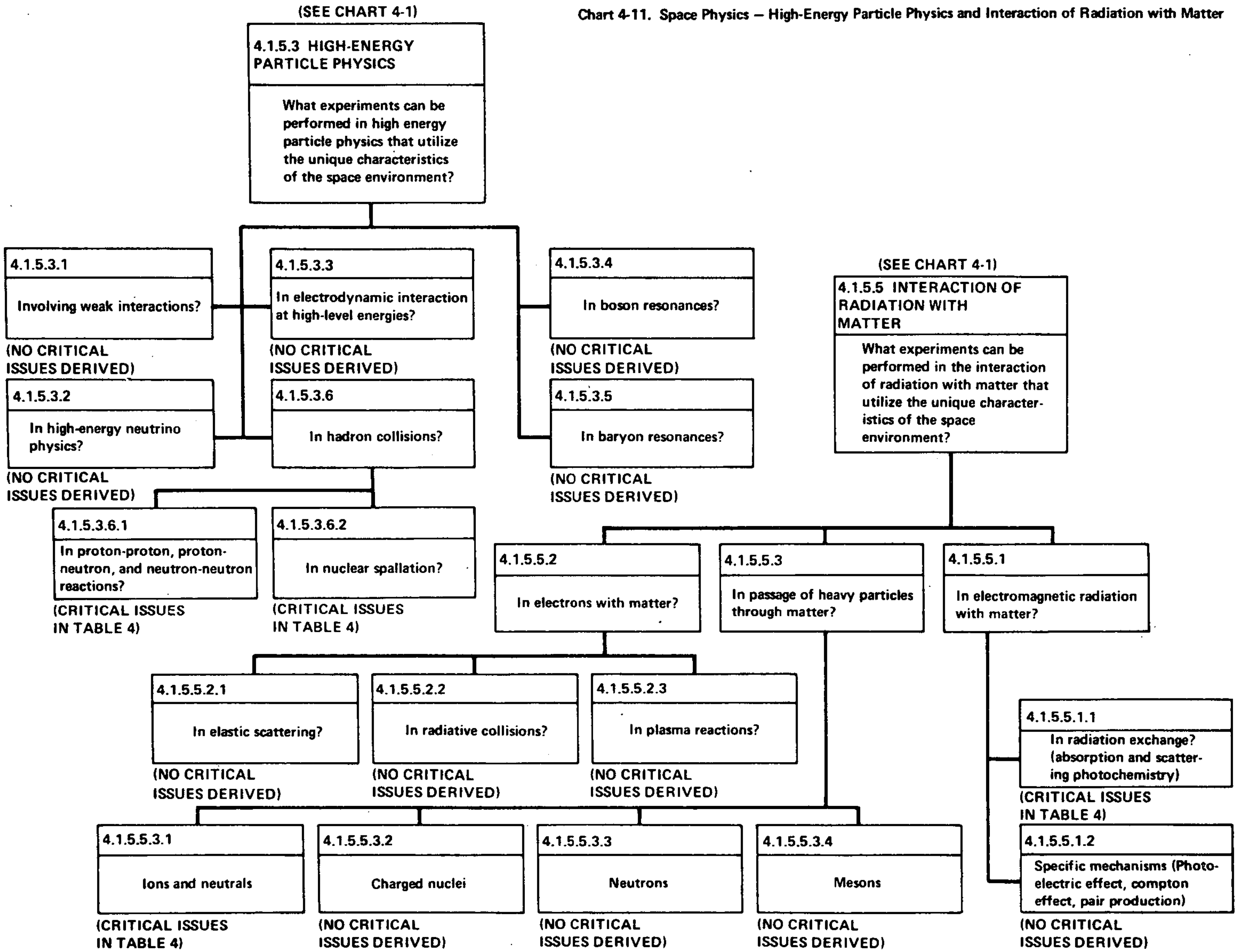


Chart 4-12. Space Physics – Solid-State Physics

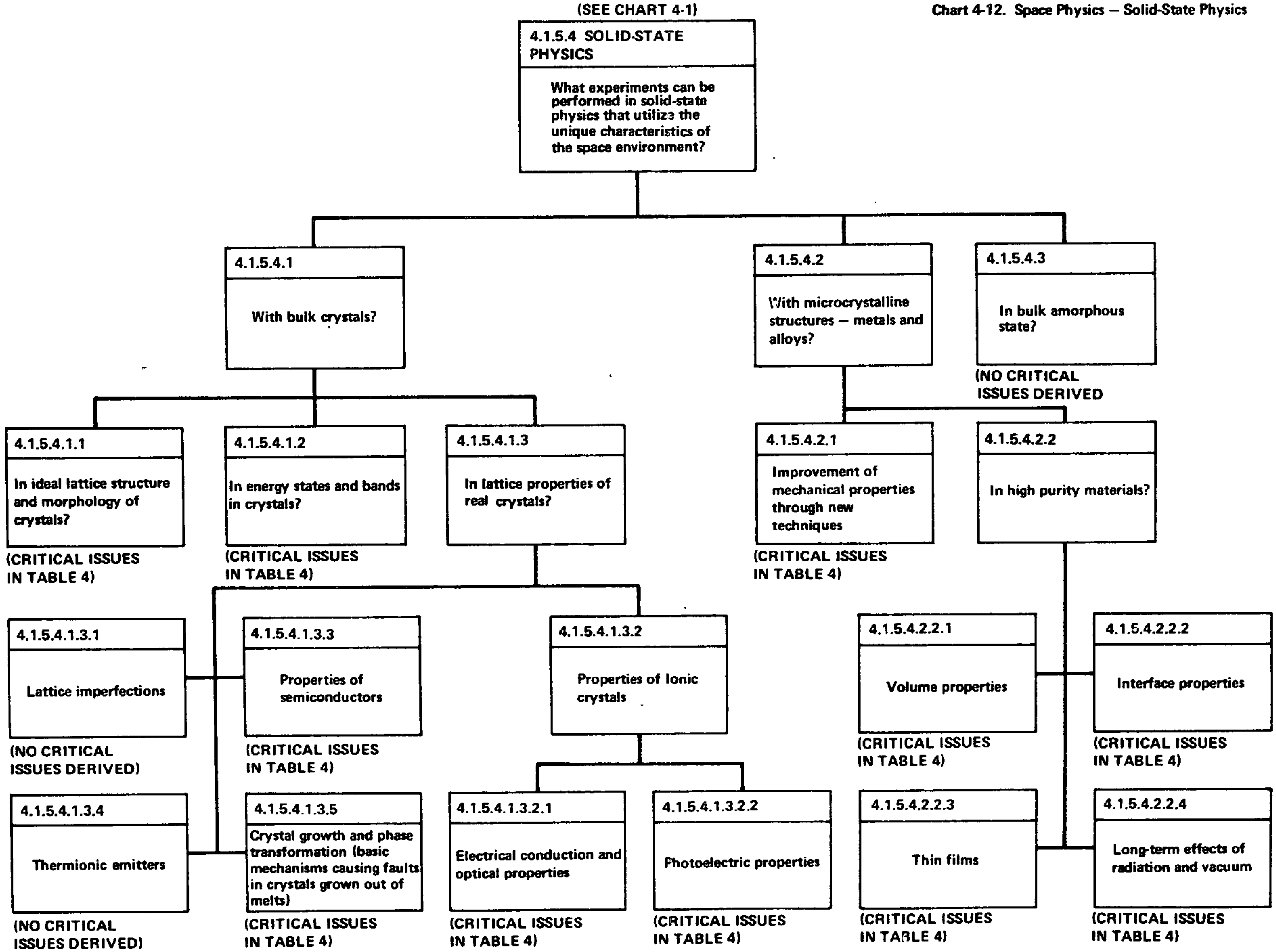


Chart 4-13. Space Physics – Plasma Physics

(SEE CHART 4-1)

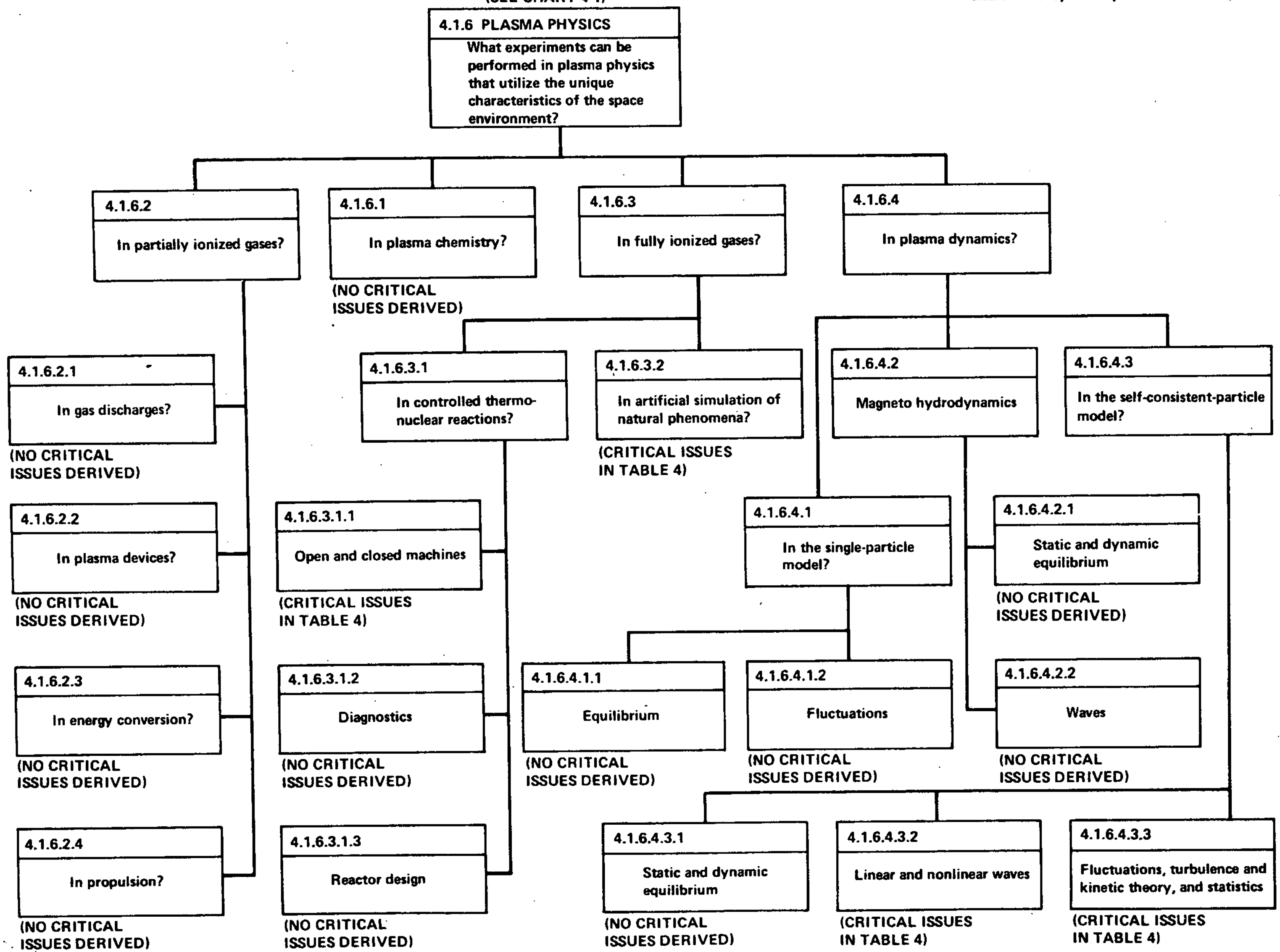


Chart 4-14. Space Physics – Direct Sensing of Local Space Environment

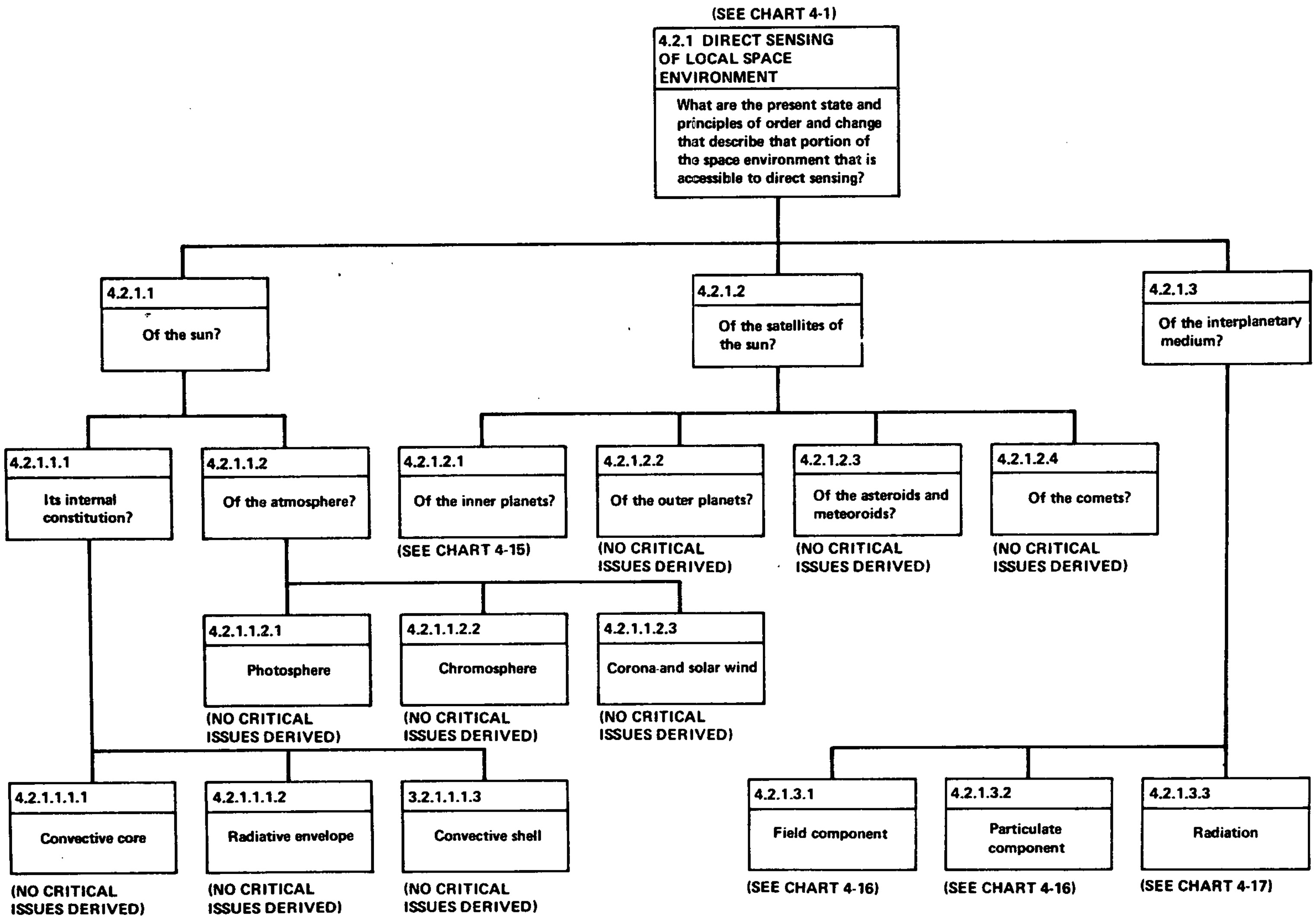


Chart 4-15. Space Physics – Direct Sensing of the Inner Planets

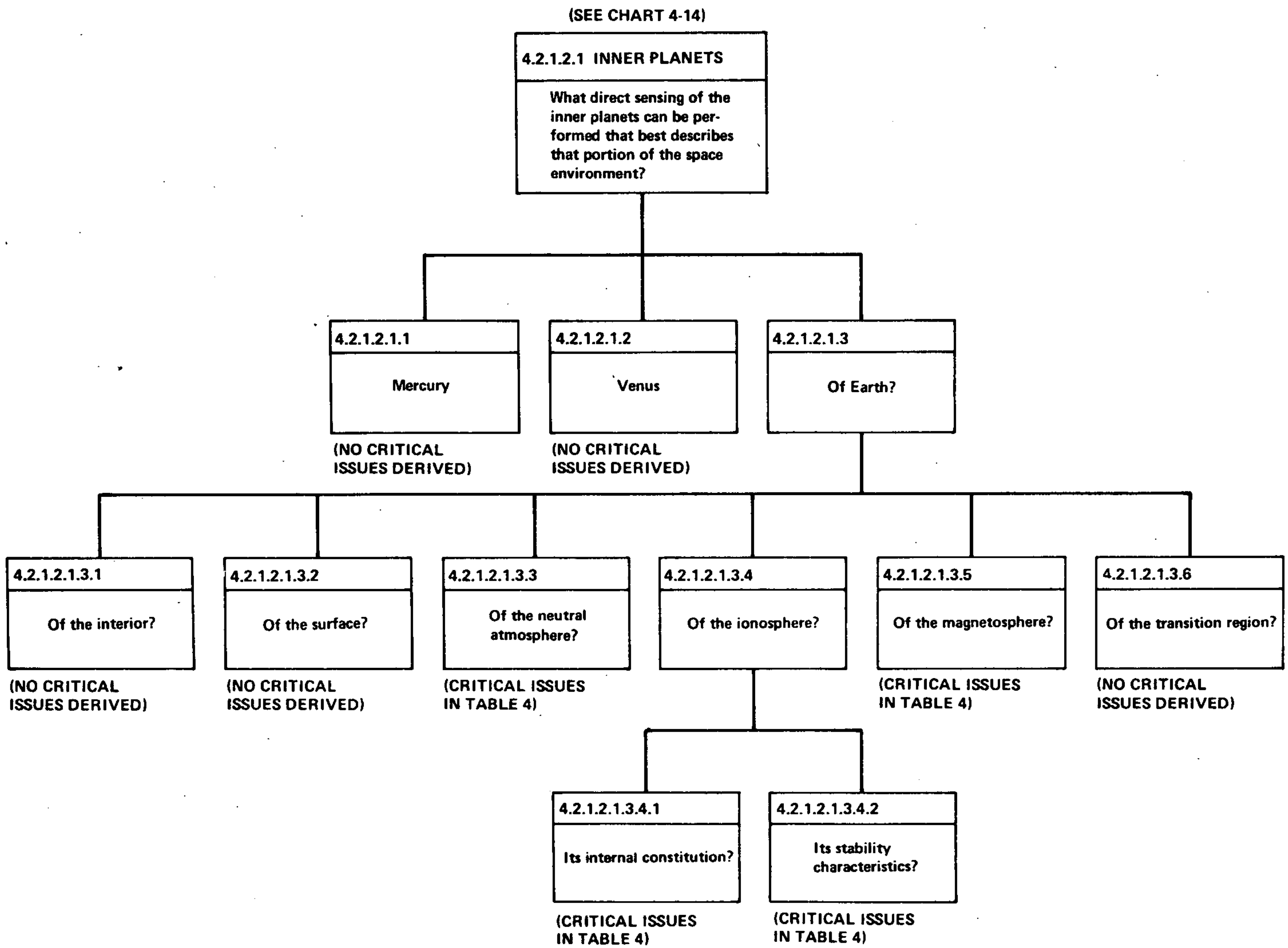


Chart 4-16. Space Physics – Direct Sensing of the Field Component and Particulate Component of the Interplanetary Medium

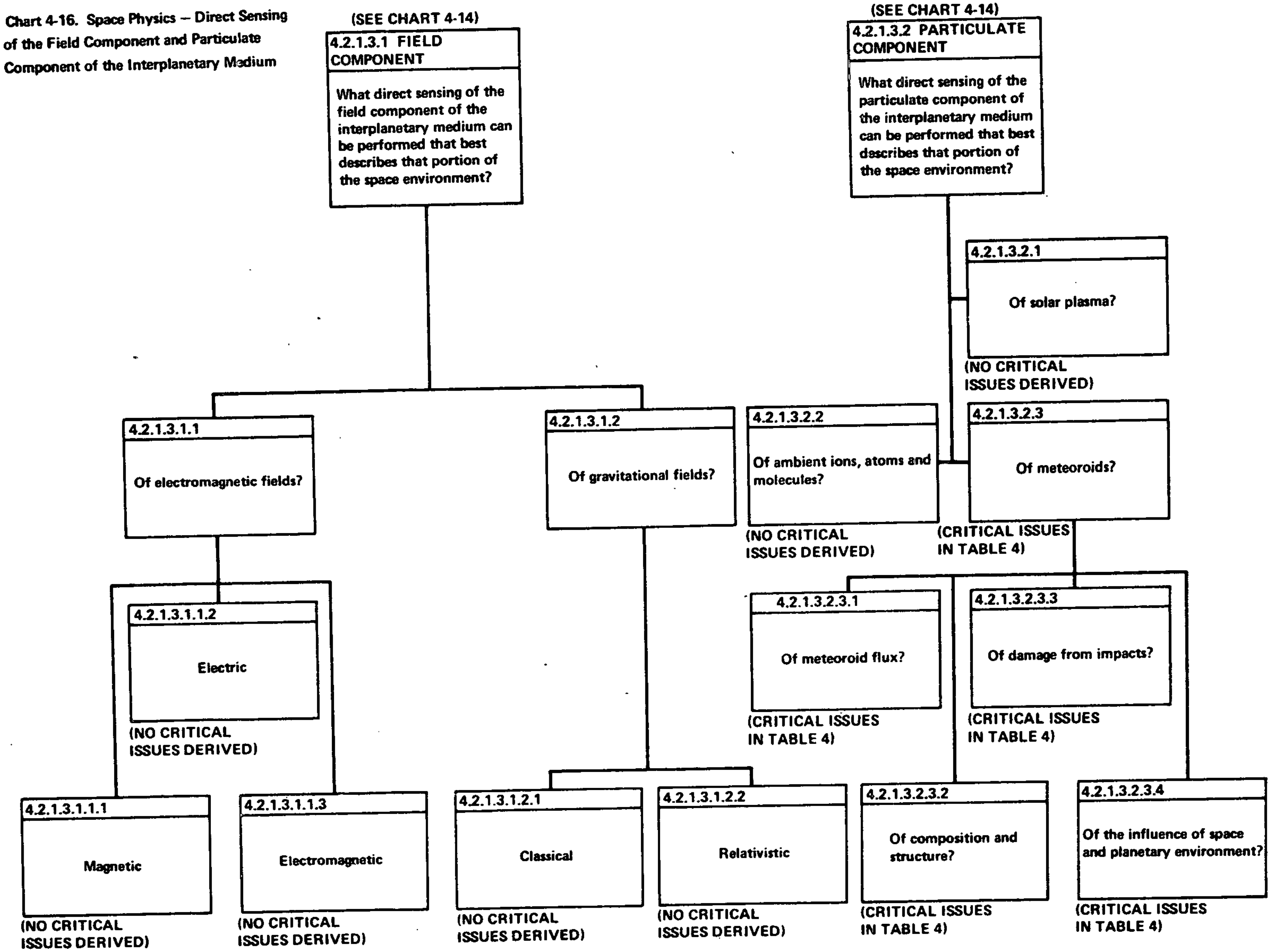
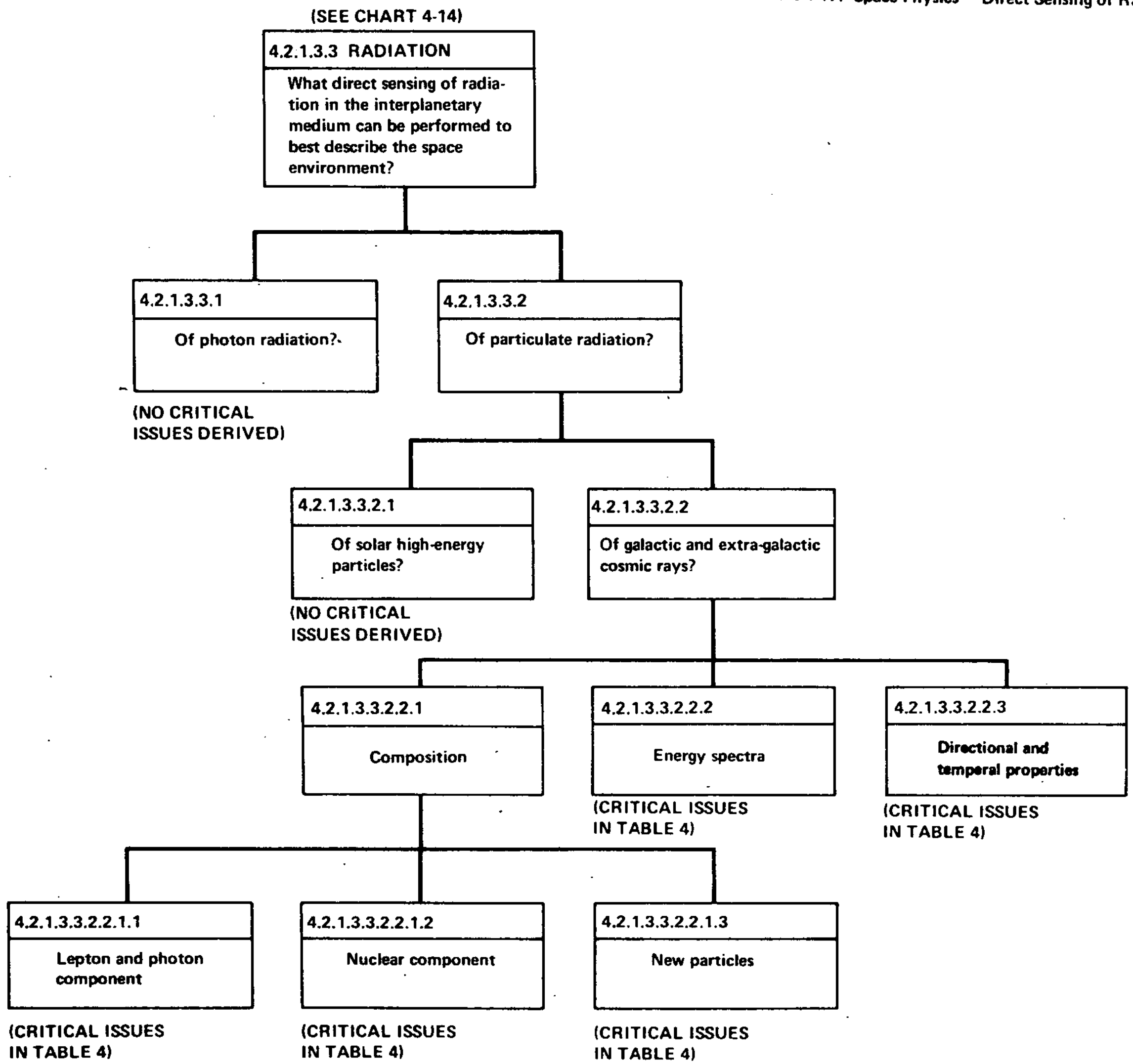


Chart 4-17. Space Physics – Direct Sensing of Radiation in the Interplanetary Medium



APPENDIX B

CRITICAL ISSUES

SPACE PHYSICS

B-4-1

TABLE 4

SPACE PHYSICS

4.1 <u>PHYSICS EXPERIMENTS UTILIZING SPACE</u>

4.1.1 CLASSICAL MECHANICS, RELATIVITY AND GRAVITATION

4.1.1.1 <u>Classical Mechanics</u>

4.1.1.1.1 Statics

4.1.1.1.2 Dynamics

4.1.1.1.2.1 Point Mass Motion

4.1.1.1.2.2 Central Force Fields

.1 Can accumulations of matter be observed near the Lagrangian Libration points? UM

.2 Can the solar quadrupole moment be measured by observations of Planetary orbits? UM

4.1.1.1.2.3 Rigid Body Motions

4.1.1.2 <u>Special Relativity</u>

4.1.1.2.1 Kinematics and Lorentz Transformation

4 1. 1. 2. 2 Dynamics and the Inertia of Energy

4. 1. 1. 2. 3 Optics and Moving Bodies

- .1 Velocity of Light
- .2 Doppler Effect
- .3 Aberration of Light

4. 1. 1. 3 General Relativity

4. 1. 1. 3. 1 Principle of Equivalence

- .1 Are inertial mass and gravitational mass exactly equivalent? UM

4. 1. 1. 3. 2 The Metric of the Space Time Continuum

- .1 Is space-time isotropic? SA

4. 1. 1. 3. 3 Gravitation

4. 1. 1. 3. 3. 1 New Effects

- .1 What is the influence of space curvature on planetary orbits? NS/UM
- .2 Does space-time curvature influence the precession rate of gyroscopes? UM/OP
- .3 What are the effects of gravitational fields on electromagnetic waves? UM/OP

4. 1. 1. 3. 3. 2 Generalized Formulation

- .1 How can measurement of the gravitational constant be improved? UM
- .2 Which relativistic theory of gravitation is correct? UM/OP
  - .1 Einstein's General Theory of Relativity (Tensor-Tensor Theory)
  - .2 Dicke-Brans Theory (Tensor-Scalar Theory)

.3 Other Jordan-Type Theories Incorporating the Principle of Equivalences

.3 Are gravitational forces subject to systematic change or fluctuation? UM

4.1.1.3.3.3 Gravity Waves

.1 How can their intensity and characteristics be measured? NS, OP

.2 What are the intensity range, direction of incidence, and typical temporal behavior? NS, OP

.3 What is their origin? NS, OP

4.1.1.3.4 Cosmological Implications

4.1.1.3.5 Optical Deductions and Confirmations

4.1.1.3.6 Unified Field Theory

4.1.2 ELECTROMAGNETISM (INCLUDING OPTICS)

4.1.3 HEAT, THERMODYNAMICS, AND STATISTICAL MECHANICS

4.1.3.1 Principles of Thermodynamics

4.1.3.1.1 Phenomenological Principles

4.1.3.1.1.1 Laws of Thermodynamics

4.1.3.1.1.1.1 Laws of Energy Conversion

.1 Is the total energy conserved in the universe? NS,SA

4.1.3.1.1.1.2 Law of Entropy

.1 Is the entropy of the universe steadily increasing? NS,SA

.2 Can it locally decrease? NS,SA

4.1.3.1.1.2 Chemical Thermodynamics Reaction Kinetics

4.1.3.1.1.2.1 Equilibrium Thermodynamics

4.1.3.1.1.2.2 Nonequilibrium Thermodynamics

4.1.3.1.1.2.3 Flame Chemistry

.1 How is the chemistry of flames and combustion process influenced by a gravity field? 4-P/C-1

.2 How are the characteristics of explosive phenomena influenced by the space environment? UM

4.1.3.1.2 Equations of State

4.1.3.1.2.1 Equilibrium Conditions

4.1.3.1.2.1.1 Dilute and Moderately Dense Gases

4.1.3.1.2.1.2 Dense Gases and Liquids

.1 What are the thermodynamic properties and density profiles of liquids in the critical region under zero-G conditions? 4-P/C-2

.2 How do liquid-vapor interfaces behave in reduced gravity as a function of time? 4-P/C-2

.3 What are the characteristics of boiling and condensation in zero-G? 4-P/C-3

.4 What parameters characterize heat transfer in nucleate boiling? 4-P/C-3

4.1.3.1.2.1.3 Solids

.1 How do metals sublime and condense in zero-G? 4-P/C-8

4.1.3.1.2.2 Nonequilibrium Conditions in Gases

.1 How do clouds expand in the space environment? UM

.2 What is the density, chemistry, and energy distribution in expanding gas clouds? UM

4.1.3.1.2.3 Extreme Conditions

.1 High Pressures

.2 High Temperatures

4.1.3.1.3 Surface Tension Phenomena

4.1.3.1.3.1 Capillary

4.1.3.1.3.2 Adsorption

4.1.3.1.3.3 Interfaces Between Liquids and Solids

4.1.3.1.3.4 Superfluid Films

.1 How do superfluids behave in the weightless state? 4-P/C-11

4.1.3.1.4 Transport properties (Mean Free Path Phenomena)

4.1.3.1.4.1 Diffusion

.1 How do gases diffuse through porous media into a vacuum over the flow range from continuum to free molecular? NS

4.1.3.1.4.2 Viscosity

.1 What is the viscous behavior of superfluids in space? NS

4.1.3.1.4.3 Thermal Conductivity

.1 How is thermal conductivity and diffusivity of gases and liquids influenced by zero-G? NS

.2 How are free and forced convection influenced by zero-G? 4-P/C-3

.3 How is boiling-heat transfer influenced by zero-G? 4-P/C-3

4.1.3.2 <u>Principles of Kinetic Theory and Statistical Mechanics</u>

4.1.3.2.1 Chemical Kinetics

.1 What is the behavior of chemical reactions in the absence of gravity? Are there any effects? 4-P/C-1

.2 How do chemical reactions occur in the absence of walls? UM

4.1.3.2.2 Equilibrium Distributions

4.1.3.2.3 Nonequilibrium Distributions

.1 How are energy states among particles distributed in expanding gases? UM

.2 What is the energy and density distribution among particles in low-pressure expanding gas clouds into a vacuum? UM

.3 What is the energy and density distribution in high-pressure waves? NS

.4 What kind of random or periodic fluctuations exist in ensembles of particles? NS

4.1.3.3 <u>Thermal Properties of Matter</u>

4.1.3.3.1 Phase Transitions

4.1.3.3.1.1 Melting/Solidification

4.1.3.3.1.2 Vaporization/Condensation

.1 How are phase-change phenomena affected by the presence of electric and magnetic fields in low- and zero-G environment? Can such fields be used for controlling phase changes? 4-P/C-5

4.1.3.3.1.3 Solid-Solid

4.1.3.3.2 Caloric Properties of Matter

4.1.3.3.2.1 Specific Heat

4.1.3.3.2.2 Conductivity of Heat

.1 How is heat transferred and energy dissipated in a rotating liquid in low- or zero-G environment? NS

4.1.3.3.3 Heat Radiation

4.1.3.3.3.1 Laws of Radiative Emission and Absorption

4.1.3.3.3.2 Radiative Properties of Matter

4.1.3.3.3.3 Radiative Heat Transfer

4.1.3.3.3.3.1 What is the nature of Surface-to-Surface Heat Exchange? NS

4.1.3.3.3.3.2 How is heat radiatively transferred between Absorbing and Self-Emitting Media? NS

4.1.4 DEFORMABLE BODIES

4.1.4.1 Solid Mechanics

4.1.4.1.1 The Kinematics of Deformable Bodies

4.1.4.1.2 The Statics of Deformable Bodies

4.1.4.1.2.1 Stress-Strain Relations

.1 What are the mechanical properties of uniformly mixed composite materials, such as whiskers suspended in a metal matrix? NS

.2 Do compacted powders and compounds processed in the space environment behave identically with those processed in the Earth environment? NS

4.1.4.1.2.2 Time-Dependent Property Changes of Structural Materials, Fatigue

4.1.4.1.3 The Dynamics of Deformable Bodies

4.1.4.2 <u>Fluid Mechanics</u>

4.1.4.2.1 The Statics of Fluids

4.1.4.2.1.1 Gravity-Dependent Surface Phenomena of Fluids in Stationary Liquids

.1 What is the equilibrium configuration of a rotating liquid as a function of gravitational field? 4-P/C-2

.2 What are the exact shapes and surface properties of free-cast materials? 4-P/C-6

.3 What are the oscillatory relaxation times of liquids in zero-G as function of mass and material properties? 4-P/C-2

.4 What are the oscillation periods and shapes of free liquid drops and globules in zero-G? 4-P/C-2

.5 What configurations do liquids assume under zero-G in specific containers? 4-P/C-2

.6 How does the presence of electric and magnetic fields affect the dynamic and static behavior of dielectric and conducting liquids in zero- or low-gravity environment? 4-P/C-5

4.1.4.2.1.2 Material Forming Process in Zero-G Controlled by Action of Molecular Forces

.1 How are free shapes and the properties of melts influenced by cohesion and/or surface tension? 4-P/C-6

.2 What are the geometrical tolerances of free-cast bodies? NS

.3 What is the microsurface structure of free-cast bodies? NS

4.1.4.2.2 Inviscid Fluids With Fluid Continuous Flow

4.1.4.2.3 With Viscous Fluid

4.1.4.2.3.1 Fluid Discontinuous Flow

.1 How does the capillary flow in zero-G depend on the properties of liquids and surfaces? 4-P/C-10

.2 What is the dynamical behavior of solid particles in a fluid zero-G environment? NS

4.1.4.2.3.2 Vortex Flow

.1 What are the characteristics of vortices in a zero-G environment? 4-P/C-2

.2 What is the viscous behavior and the self-diffusivity in high-pressure gases in zero-G? NS

4.1.4.2.3.3 Solid-Solid and Solid-Liquid Systems

.1 How can structures of uniform density of suspended materials be achieved in a zero-G environment? 4-P/C-4

.2 Can the space environment be effectively used to achieve castings with specific density distributions? 4-P/C-4

.3 How is the process of adhesion or layer casting influenced by zero-G, and what are the resulting material properties? 4-P/C-8

.4 How can the space environment be used for controlled density casting? 4-P/C-4

.5 How do small particles distribute themselves in a liquid under the action of the Brownian movement in a zero-G environment? NS

4.1.4.2.3.4 Liquid-Liquid System

.1 How does liquid mixing in a gravity-free environment differ from that expected in a 1-G environment? 4-P/C-4

.2 How do free liquid droplets interact? 4-P/C-2

4.1.4.2.3.5 Liquid-Gaseous Systems

.1 How do bubbles move in a zero-G environment, and what are the acting forces? 4-P/C-3

.2 How do bubbles grow in zero-G, and what are their oscillation characteristics in a convection-free environment? 4-P/C-3

.3 Is it feasible to produce foam of glassy materials of uniform density in space? 4-P/C-4

4.1.4.2.3.6 Interface Phenomena of Liquid-Gas Systems

.1 What are the effects of zero-G on liquid releases and the size distribution of liquid globules? 4-P/C-9

4.1.4.3 <u>Wave Propagation</u>

4.1.4.3.1 Acoustics

4.1.4.3.2 Surface Waves in Ideal Fluids

.1 What are surface-wave propagation characteristics of liquids in a zero-G environment? 4-P/C-2

.2 What is the significance of Rayleigh instabilities in zero-G? 4-P/C-2

4.1.4.3.3 Waves of Expansion in Ideal Fluids

4.1.4.3.4 Wave Propagation in Dissipative Fluids

4.1.4.3.4.1 Viscosity and Heat Conduction

4.1.4.3.4.2 The Generation and Propagation of Shock Waves

4.1.4.3.5 Wave Propagation in Solids

4.1.4.3.5.1 Shear Waves

4.1.4.3.5.2 Longitudinal Waves in Solids

4.1.4.3.5.3 Transverse Waves in Solids

4.1.4.4 Rheology

4.1.4.4.1 The Rheological Properties of Solids

4.1.4.4.1.1 Intrinsic Properties (Elasticity, Viscosity, Plasticity, and Strength)

.1 Can space be used to improve the quality of glass materials? 4-P/C-6

.2 Can space be used to cast better lenses and glass blanks? 4-P/C-6

4.1.4.4.1.2 Microrheology (Structural Viscosity)

4.1.4.4.2 Second-Order Effects in Elasticity and Viscosity

4.1.5.1 Atomistic Structure of Matter

4.1.5.1.1 Energy Levels, Radiative Emission, Excitation, and Absorption Processes of Atoms and Molecules[1]

---

1. Theoretical concepts which are frequently used in atomic and molecular physics for the theoretical interpretation of certain properties such as radiative emission, absorption and excitation processes are listed:

   - Atomic Spectra
   - Quantum Mechanics
   - Periodic Tables
   - Molecular Spectra
   - Molecular Models
   - Atomic Masses
   - Atomic Constraints
   - Atomic Models

Atomic and molecular spectra can in principle be explained by use of quantum mechanics. Some basic chemical and spectral properties can be qualitatively understood by rather simple concepts, such as the periodic system and classical atomic particle models. Any of the theoretical concepts shown in the above list--or a combination of them--could make a contribution to the understanding of atomic or molecular properties. Therefore these theoretical tools have been treated as a whole.

4.1.5.1.1.1 Intrinsic spectral characteristics

4.1.5.1.1.1.1 X-ray
4.1.5.1.1.1.2 U.V.
4.1.5.1.1.1.3 Visible
4.1.5.1.1.1.4 Infrared
4.1.5.1.1.1.5 Microwave

4.1.5.1.1.2 Line broadening and continuum radiation, atomic spectral shapes

4.1.5.1.1.2.1 Collision broadening
4.1.5.1.1.2.2 Doppler broadening
4.1.5.1.1.2.3 Stark broadening
4.1.5.1.1.2.4 Bremsstrahlung

4.1.5.1.1.3 Spectral Frequency Shifts

4.1.5.1.1.3.1 Doppler-effect
4.1.5.1.1.3.2 Stark-Effect
4.1.5.1.1.3.3 Paschen-Back effect
4.1.5.1.1.3.4 Zeeman-effect
4.1.5.1.1.3.5 Gravitational shifting of spectral features
4.1.5.1.1.3.6 The cosmological red shift

4.1.5.1.1.4 The hyperfine structure of atomic spectra

4.1.5.1.2 Chemical Properties

4.1.5.1.2.1 Atomic and Molecular Reactions

.1 What are the ionization rates by solar radiation of barium, lithium, and cesium? PS

4.1.5.1.2.2 Chemical Reactions

.1 What noble-gas chemistry can be performed in the high vacuum of space? PS

.2 What is the behavior of monatomic oxygen? PS

.3 How can the rate of dissociative recombination of oxygen be measured in space? PS

.4 What free radicals can be formed using the high vacuum and ultra-violet present in space? PS

.5 What are the recombination coefficients for ionized oxygen and monatomic oxygen? PS

4.1.5.1.2.3 Kinetic Models

4.1.5.2 Nuclear Physics

4.1.5.2.1 Nuclear Systematics

4.1.5.2.2 Nuclear Models

4.1.5.2.3 Nuclear Reactions

4.1.5.2.4 Nuclear Decay

4.1.5.2.4.1 α-Decay

4.1.5.2.4.2 β-Decay

4.1.5.2.4.3 Radiative Decay

4.1.5.2.4.4 Fission and Neutron Emission

.1 Can space be used for breeding fissionable nuclear fuels? PS

4.1.5.2.5 Low-Energy Accelerators

4.1.5.2.5.1 Cockroft Walton Generator

4.1.5.2.5.2 Van De Graaff Generator

4.1.5.2.5.3 Linear Accelerators

.1 How can electron-beam accelerators be used in orbit to simulate certain geophysical phenomena? 4-PP-2

4.1.5.2.5.4 Cyclotron

4.1.5.3 <u>High-Energy Particle Physics</u>

4.1.5.3.1 Weak Interactions

4.1.5.3.2 High-Energy Neutrino Physics

4.1.5.3.3 Electrodynamic Interaction at High Energies

4.1.5.3.4 Boson Resonances

4.1.5.3.5 Baryon Resonances

4.1.5.3.6 Hadron Collisions

4.1.5.3.6.1 Proton-Proton, Proton-Neutron, and Neutron-Neutron Reactions

.1 What are the total p-p, p-n, and n-n cross-sections at high energies? 4-CR-9

.2 What are the differential p-p, p-n, and n-n cross-sections at high energies? 4-CR-9

.3 What are the angular and energy distributions of secondaries produced as a function of incoming proton and alpha-particle energies? 4-CR-9

4.1.5.3.6.2 Nuclear Spallation

.1 What are the spallation cross-sections of heavy nuclei on hydrogen? 4-CR-10

.2 What is the multiplicity of charged-particle production from nuclear-spallation reactions? 4-CR-10

.3 What is the energy distribution of the outgoing particles from nuclear-spallation reaction? 4-CR-10

.4 What is the angular distribution of the outgoing particles from nuclear-spallation reactions? 4-CR-10

4.1.5.4 Solid-State Physics

4.1.5.4.1 Bulk Crystals

4.1.5.4.1.1 Ideal Lattice Structure and Morphology of Crystals

.1 Can whisker growth be improved in zero-G? 4-P/C-6

4.1.5.4.1.2 Energy States and Bands in Crystals

.1 What are the effects of gravitational potentials on low-lying quantum states at extremely low temperatures? UM

4.1.5.4.1.3 Lattice Properties of Real Crystals

4.1.5.4.1.3.1 Lattice Imperfections

4.1.5.4.1.3.2 Properties of Ionic Crystals

4.1.5.4.1.3.2.1 Electrical Conduction Properties and Optical Properties

.1 How are electrical and optical properties of semiconductor surfaces influenced by ultraclean environment? NS

4.1.5.4.1.3.2.2 Photoelectric Properties

.1 How are electronic surface-emission phenomena influenced by the cleanliness of space? NS

.2 What are the secondary electron-emission phenomena occurring on very clean surfaces? NS

4.1.5.4.1.3.3 Properties of Semiconductors

.1 How are the properties of semiconductors influenced by space radiation? NS

4.1.5.4.1.3.4 Thermionic Emitters

4.1.5.4.1.3.5 Crystal Growth and Phase Transformation

.1 What are the effects of gravity on solidification and crystal growth out of melts? 4-P/C-6

.2 How can these effects be utilized to improve the size, quality, and purity of industrial-quality crystals? 4-P/C-6

.3 Is it possible to grow giant single crystals of high perfection? 4-P/C-6

.4 How does weight-stress elimination influence the quality of crystals grown out of melts? 4-P/C-6

.5 What are the observable dependent parameters effected by gravity? 4-P/C-6

.6 What are the potential advantages of zone refining of single crystal in zero-G? 4-P/C-6

4.1.5.4.2 Microcrystalline Structures - Metals and Alloys

4.1.5.4.2.1 Improvement of Mechanical Properties Through New Techniques

.1 How can the process of levitation melting be improved? 4-P/C-7

.2 How can the process of heat treatment be improved? NS

.3 Is it feasible to produce metal foam of uniform density in space? 4-P/C-4

.4 How can the process of vacuum melting and casting be improved in the space environment? 4-P/C-7

4.1.5.4.2.2 High-Purity Materials

4.1.5.4.2.2.1 Volume Properties

.1 How can vacuum and natural levitation in space be used to obtain high-purity materials? 4-P/C-7

.2 What are the properties of extremely high purity materials? NS

4.1.5.4.2.2.2 Interface Properties

.1 How are phenomena of surface chemistry affected by ultraclean surfaces? NS

.2 What are the catalytic effects of very clean surfaces? NS

.3 What are the surface friction coefficients of various ultraclean materials? NS

.4 What are the contact properties of ultraclean materials? NS

.5 What is the "sticking probability" of gas molecules on clean surfaces as a function of the coverage? NS

.6 What are the adsorptive properties of ultraclean surfaces? NS

.7 What is the adsorption energy between a metallic surface and an absorbed gas? NS

.8 What are the true work functions of pure metals? NS

4.1.5.4.2.2.3 Thin Films

.1 Is the space environment an effective medium for generating thin films by use of sputtering or evaporation techniques? 4-P/C-8

.2 Is the space environment an effective medium for surface deposition and surface-tension drawing of thin films? 4-P/C-8

4.1.5.4.2.2.4 Long-term Effects of Radiation and Vacuum

.1 Is the fatigue behavior of structural materials in space similar to that observed on ground? NS

4.1.5.4.3 Bulk Amorphous State

4.1.5.5 Interaction of Radiation With Matter

4.1.5.5.1 Electromagnetic Radiation With Matter

4.1.5.5.1.1 Radiation Exchange (Absorption and Scattering; Photochemistry)

.1 What are the absorption coefficients and the cross-section for photon irradiation of monatomic oxygen? PS

.2 What are the absorption cross-sections of ions, free radicals, and molecules in the vacuum ultraviolet? PS

4.1.5.5.1.2 Mechanisms (Photoelectric Effect, Compton Effect, Pair Production)

4.1.5.5.2 Electrons with Matter

4.1.5.5.3 Passage of Heavy Particles Through Matter

4.1.5.5.3.1 Ions and Neutrals

.1 What are the cross-sections for ionization by electrons, protons, alphas, and electrons of monatomic oxygen? PS

4.1.6 PLASMA PHYSICS

4.1.6.1 Plasma Chemistry

4.1.6.2 Partially Ionized Gases

4.1.6.3 Fully Ionized Gases

4.1.6.3.1 Controlled Thermonuclear Reactions

4.1.6.3.1.1 Plasma Machines

.1 How do magnetospheric observations correlate with laboratory mirror experiments? 4-PP-2

.2 Are the end-plate precipitation patterns observed in mirror machines in any way analogous to precipitation patterns observed in the aurora? 4-PP-4

.3 Are the suprathermal particles observed in space produced by processes similar to those that occur in high-energy laboratory plasma-physics experiments? 4-PP-2

.4 Can space be used as a site for thermonuclear fusion devices such as the levitron? PS

4.1.6.3.1.2 Diagnostics

4.1.6.3.1.3 Reactor Design

4.1.6.3.2 Artificial Simulation of Natural Phenomena

.1 What are the relations between the Terrella experiment and bow-shock observations? NS

4.1.6.4 Plasma Dynamics

4.1.6.4.1 Single-Particle Model

4.1.6.4.2 Magnetohydrodynamics

4.1.6.4.3 Self-Consistent-Particle Model

4.1.6.4.3.1 Static and Dynamic Equilibrium

4.1.6.4.3.2 Linear and Nonlinear Waves

.1 Can the long wavelengths possible in space be used to study the nature of the plasma waves? 4-PP-3

.2 Can Alfvén waves be propagated in the magnetosphere or ionosphere? 4-PP-1,3

.3 Can whistler-mode propagation experiments be performed in the magnetosphere? 4-PP-3

.4 Can drift waves be studied using the drift surfaces in the magnetosphere? 4-PP-3

.5 Can nonlinear waves be produced along lines of the force by injecting small-amplitude waves? 4-PP-3

.6 Is the bow shock similar to laboratory collisionless shocks? Are the dissipative mechanisms the same? 4-PP-3

4.1.6.4.3.3 Fluctuations, Turbulence, Kinetic Theory, and Statistics

.1 Can the Earth's magnetosphere be used to determine the deflection of electromagnetic waves in traversing a fluctuating plasma? 4-PP-3

.2 Can fluctuations in the magnetosphere or interplanetary plasma be correlated with fluctuations in the phase patterns (twinkling) in long base-line interferometry of radio sources? SA

.3 Are unexpected effects produced by fluctuating plasmas near the Sun, and how do these effects influence experiments of gravitational wave bending and delay? NS

.4 How does a fluctuating plasma impact a magnetic field. Does the plasma exert a drag on the field lines? NS

4.2 PHYSICS OF THE SPACE ENVIRONMENT

4.2.1 DIRECT SENSING OF THE LOCAL SPACE ENVIRONMENT

4.2.1.1 The Sun

4.2.1.1.1 Internal Constitution

4.2.1.1.2 Atmosphere

4.2.1.2 Solar Satellites

4.2.1.2.1 Inner Planets

4.2.1.2.1.1 Mercury

4.2.1.2.1.2 Venus

4.2.1.2.1.3 Earth

4.2.1.2.1.3.1 Interior

4.2.1.2.1.3.2 Surface

4.2.1.2.1.3.3 Neutral Atmosphere

.1 To what extent do the Earth's ionosphere and magnetosphere affect the fractionation and balance of hydrogen and helium in the Earth's atmosphere? 4-PP-4

4.2.1.2.1.3.4 Ionosphere

4.2.1.2.1.3.4.1 Internal Constitution

.1 What is the vector magnetic field present at each point in the ionosphere? 4-PP-2

.1.1 Are field lines in the polar regions open or closed? 4-PP-2

.1.2 Can conjugate point locations be determined to 1 km or better? 4-PP-2

.1.3 Are there diurnal or seasonal variations in conjugate point locations? 4-PP-2

.2 What is the electron density in the ionosphere? 4-PP-1, 2, 3

.3 What ionic species are present in the ionosphere? 4-PP-1, 2, 3

.3.1 What is the density of each ionic species present in the ionosphere? 4-PP-1, 2, 3

.3.2 What is the temperature of each ionic species present in the ionosphere? 4-PP-1, 2, 3

.4 What is the electron temperature in the ionosphere? 4-PP-1,2,3

.5 What waves are present in the ionosphere? 4-PP-2,3

.5.1 What effect does incoherent Cerenkov radiation have upon the level of observed ionospheric emissions? 4-PP-2,3

.5.2 How do VLF waves interact with naturally appearing and artificially produced charged particles in the upper ionosphere and magnetosphere? 4-PP-2,3

.5.3 How are VLF waves transmitted through the upper ionosphere? 4-PP-2,3

.5.4 How can artificially produced whistlers be detected from the ground and from other spacecraft, and how well correlate pertinent measurements with predictions of whistler theory? 4-PP-3

4.2.1.2.1.3.4.2 Stability Characteristics

.1 Can chemicals be released into the ionosphere to alter significantly the local attachments and recombination rates, thus perturbing ionospheric characteristics? 4-PP-3

.1.1 What is the luminous efficiency of ion beams interacting with the upper atmosphere? 4-PP-2

.2 What are the consequences of irradiating the ionosphere with high-intensity electromagnetic waves? 4-PP-3

.2.1 What RF power and frequencies are required to produce substantial heating of the ionosphere? 4-PP-3

.3 Can the ambient electron density in the lower ionosphere at auroral latitudes be sufficiently enhanced to trigger an aurora? 4-PP-4

.4 What are the processes determining the production and loss of ionospheric plasma? 4-PP-3

.5 Can an artificial aurora be produced by the injection of high-energy protons from a spacecraft? Which diagnostics are required to relate such an artificial aurora with a natural one? 4-PP-4

4.2.1.2.1.3.5 Magnetosphere

.1 Are the energetic particles in the Earth's magnetosphere solar or terrestrial in origin? 4-PP-2

.1.1 Does magnetic field annihilation occur in the magnetospheric tail to give magnetic particles? 4-PP-2

.1.2 Where does the solar-wind plasma enter the magnetosphere, and how does it flow toward the Earth? 4-PP-2

.1.2.1 What are the plasma-flow characteristics in specific regions of the magnetosphere, such as the magnetosheath? 4-PP-2

.1.3 Does natural injection occur from the interplanetary medium into the magnetosphere? 4-PP-2

.1.4 Can tracer elements be injected to permit unambiguous separation of particle gain and loss processes? 4-PP-2

.2 How can the magnetosphere be investigated by the injection of low-intensity beams into the space plasma? 4-PP-2,3

.2.1 Can electron, proton, or plasma beams be injected into the magnetosphere to enhance naturally occurring instabilities? 4-PP-2,3

.2.2 What conditions does the environment impose on a particle beam injected as a diagnostic tool into the magnetosphere? 4-PP-2

.3 What information about the environment can be derived from high-altitude detonations? What type of detonations would be useful for these investigations? 4-PP-2

.3.1 Can chemicals be released in the magnetospheric tail to determine the structure of magnetic field lines? 4-PP-2

.3.1.1 What is the geometry of magnetic field lines at specific locations of the space environment? 4-PP-2

.3.1.2 How can it be measured? 4-PP-2

.3.1.3 What is the geometry of electric field lines at the same locations? 4-PP-2

.3.1.4 How can it be measured? 4-PP-2

.4 How stable is the magnetosphere, i.e., what is the lifetime of an ion in the magnetosphere? 4-PP-2

.4.1 Is the tearing mode instability active in the magnetospheric tail? If not, what determines the rate of merging? 4-PP-2

.4.2 Are flute, loss cone, or ion cyclotron instabilities active in the magnetosphere? 4-PP-2

.4.3 Can electric fields exist parallel to the lines of force in the magnetosphere? 4-PP-2,3

.4.3.1 Is the conductivity infinite along lines of force in the magnetosphere, or do plasma instabilities impose a finite conductivity? 4-PP-3

.4.4 Is the nondipole nature of the Earth's field sufficient to insure particle instability? 4-PP-2

.4.5 What are the fluctuating electric and magnetic field patterns in the Sunward portion of the Earth's magnetosphere? 4-PP-2,3

.4.5.1 What is the nature of transient fluctuations in the electromagnetic fields and the electron population? 4-PP-2,3

.4.5.2 Are electrons traveling in orderly fashion along lines of force, or are they being disturbed by fluctuating electric or magnetic fields? 4-PP-2,3

.4.6 What is the role of Bohm diffusion in the magnetospheric phenomena? 4-PP-2,3

.4.6.1 Is radial diffusion of trapped magnetospheric electrons driven by drift period resonances with magnetic oscillations, or by Bohm diffusion. 4-PP-2,3

.5 What waves can be propagated in the magnetosphere? 4-PP-3

.5.1 What are the dispersions relations in the magnetosphere? 4-PP-3

.5.2 Can trapped energetic particles be accelerated by electromagnetic irradiations? 4-PP-2

.5.2.1 What radiation power is required to reduce significantly the level of dangerous radiation reaching astronauts? 4-PP-2

.5.3 Can ion cyclotron wave propagation experiments be performed in the magnetosphere? 4-PP-3

.6 Are striations a characteristic of the space environment? Is Simon's theory valid? 4-PP-4

4.2.1.2.1.3.6 Transition Region

4.2.1.3 The Interplanetary Medium

4.2.1.3.1 Field Component

4.2.1.3.2 Particulate Components

4.2.1.3.2.1 Solar Plasma

4.2.1.3.2.2 Ambient Ions, Atoms and Molecules

4.2.1.3.2.3 Meteoroids

4.2.1.3.2.3.1 Meteoroid Flux

- .1 What are the material densities of meteoroids in the solar system? NS,UM
- .2 What are the fluxes of meteoroids in the solar system? NS,UM
- .3 What is the velocity distribution of meteoroids in the solar system? NS,UM

4.2.1.3.2.3.2 Composition and Structure

- .1 What are the composition and structure of the meteoroids in the near-Earth environment? NS,UM
- .2 What are the composition and structure of the meteoroids in the Lunar environment? UM
- .3 What are the composition and structure of meteoroids in cislunar space? UM
- .4 What are the composition and structure of meteoroids emitted by the Moon? UM

4.2.1.3.2.3.3 Damage From Impact?

- .1 How does the damage from a meteoroid depend on its mass and velocity? UM,NS
- .2 How does the damage from a meteoroid depend on its structure and composition? UM,NS

4.2.1.3.2.3.4 Influence of Space and Planetary Environment

- .1 How do cosmic rays affect the properties of meteoroids? NS
- .2 How are meteoroids ablated during their entry into the Earth's atmosphere? NS
- .3 Are there any concentrations of materials at the Earth-Sun Lagrangian points? UM
- .4 Are there any concentrations of material at the Earth-Moon Lagrangian points? UM
- .5 How is the meteoroid population influenced by proximity to planetary orbits? UM

4.2.1.3.3 Radiation

4.2.1.3.3.1 Photon Radiation

4.2.1.3.3.2 Particulate Radiation

4.2.1.3.3.2.1 Solar High-Energy Particles

4.2.1.3.3.2.2 Galactic and Extragalactic Cosmic Rays

4.2.1.3.3.2.2.1 Composition

4.2.1.3.3.2.2.1.1 Lepton and Photon Component

- .1 What is the electron-positron ratio in the primary cosmic radiation as a function of energy? 4-CR-2

4.2.1.3.3.2.2.1.2 Nuclear Component

- .1 What is the abundance of the low-mass isotopes present in cosmic radiation? 4-CR-1
- .2 What is the charge composition as a function of energy of the primary cosmic radiation? 4-CR-1

4.2.1.3.3.2.2.1.3 New Particles

.1 Are any anti-protons or anti-nuclei present in the primary cosmic rays? 4-CR-5

.2 Are there any long-lived heavy isotopes present in the cosmic rays? 4-CR-4

.3 Are any stable neutron-rich transuranic elements present in the cosmic radiation? 4-CR-4

.4 Are there any stable fractionally charged particles present in the primary cosmic radiation (quarks)? 4-CR-6

.5 Are there any particles in the cosmic rays with properties yet unknown? 4-CR-7

4.2.1.3.3.2.2.2 Energy Spectra

.1 What is the energy spectrum of gamma radiation present in the primary cosmic-ray flux? 4-CR-3

.2 What is the energy spectrum of the heavy nuclei in the primary cosmic radiation? 4-CR-1

.3 What is the energy spectrum of the primary electrons in the cosmic rays? 4-CR-2

.4 What is the energy spectrum of protons in the primary cosmic rays? 4-CR-1

.5 What is the energy spectrum of the light nuclei in the primary cosmic radiation? 4-CR-1

4.2.1.3.3.2.2.3 Directional and Temporal Properties

.1 What temporal fluctuations are present in the nuclear component of the primary cosmic-ray flux? 4-CR-1

.2 What is the spatial and temporal distribution of electrons in the primary cosmic-ray flux? 4-CR-2

.3 What is the spatial and temporal distribution of gamma rays in the primary cosmic ray flux? 4-CR-3

.4 What is the degree of anisotropy present in the nuclear component of the cosmic-ray flux? 4-CR-1

.5 What are the characteristics of the albedo particles above 100 MeV? 4-CR-8

4.2.2 INTERPRETATION OF REMOTE ENVIRONMENT THROUGH LOCAL EXPERIMENTS

4.2.3 REMOTE SENSING OF SPACE ENVIRONMENT

4.3 SPACECRAFT ENVIRONMENTAL CONDITIONS

4.3.1 ENVIRONMENTAL POLLUTION OF SPACECRAFT ENVIRONMENT

4.3.1.1 Spacecraft Surface Effects

.1 What are the effects of pressure loads and thermal gradients on various surfaces from a spacecraft engine plume in high-vacuum conditions? MS

.2 How do deposits of nonvolatile substances affect the surface properties of particle and sensing elements? PS

.3 What effect does the spacecraft potential distribution have on the wake? 4-PP-1

4.3.1.2 Spacecraft Spatial Environment

.1 How does leaking and outgassing affect the properties of the space environment? 4-PP-1

.2 How are particle measurements influenced by the satellite environment? 4-PP-1

.2.1 What are the optical properties of gaseous releases? NS

.2.2 What are the optical properties of liquid-particle dispersions? NS

.2.3 What are the optical properties of small solid particles? NS

.3 What is the chemical composition of the contaminating gases surrounding the spacecraft at various distances and angles from the spacecraft? 4-PP-1

.4 How do plasma and ion propulsion devices interact with the environment? 4-PP-1

.4.1 What are the important interaction processes occurring in plasma jets expanding into a vacuum, and what are the plume characteristics? PS

.5 What factors affect vehicle drag characteristics? 4-PP-1

4.3.2 SPACECRAFT NATURAL ENVIRONMENT

4.3.2.1 What is the configuration of the spacecraft wake?

.1 What is the lowest achievable vacuum near the spacecraft? 4-PP-1

.2 How does the spacecraft wake affect environmental measurements? 4-PP-1

.3 What effect does vehicle shape and size have on the spacecraft wake? 4-PP-1

.4 What effect does the operation of high power antennas have on the vehicle wake? 4-PP-1

.5 Are waves produced in the wake region? 4-PP-1

.6 How can subsatellites be used to measure the wake? 4-PP-1

.7 What is the electric field distribution in the near wake region of the spacecraft? 4-PP-1

.8 How does the magnetic field orientation affect the wake characteristics? 4-PP-1

.9 How will using long VLF antennas affect the spacecraft potential and wake geometry? 4-PP-1

4.3.2.2 What is the radiative environment of the spacecraft?

.1 What are the temperature conditions near the spacecraft? 4-PP-1

.2 Can the Sun be used as direct heat source for material processing? PS

.3 Can the intense solar ultraviolet be used for studies in atomic and molecular physics? PS

.4 How does solar ultraviolet irradiation affect the spacecraft potential? 4-PP-1

RESEARCH CLUSTER SYNOPSIS – SPACE PHYSICS

4-P/C-1
Effect of the Space Environment on Chemical Reactions

1. Research Objectives

This research cluster is identified within the broad category of the NASA-defined Scientific and Technological Objectives in Space Physics for exploiting the unique characteristics of space to conduct experiments not feasible on Earth, by specifically conducting studies in physics and chemistry in a space laboratory.

The scope of this research cluster is to establish the effects of near-zero gravity and the absence of walls on chemical reaction rates, including combustion phenomena as dependent upon mixing processes. The performance of these experiments in an Earth orbital experimental facility, and comparison of the results with those determined on Earth, should provide data for a comprehensive understanding of chemical kinetics and combustion processes in a near-zero-gravity environment.

2. Background and Current Status

All of the data on chemical reactions in a near-zero-gravity environment have been generated from flammability experiments using short-duration drop tower and aircraft tests. No basic theory of combustion or chemical kinetics has been developed for a zero-gravity environment. The series of flammability experiments planned for Skylab Program Experiment M-479 will provide valuable information on combustion processes in space and for expanding the scope of this research cluster. The experiments outlined in this cluster should contribute to comprehensive development for the theory of chemical kinetics and combustion processes in a near-zero-gravity environment, as well as elucidate some of the unknown combustion mechanisms on Earth. In addition, they would provide engineering data for designing future spacecraft.

3. Description of Research

This research cluster is concerned with the combustion and reaction kinetics of interacting materials. The experimental approach is to react a variety of liquids and solids in various environments to obtain the desired data. The parameters to be measured are reaction products, reaction rates, combustion products, flame front profiles, temperatures, pressures, and acceleration levels during the reaction time. The experimental procedure would be to proceed from reasonably simple experiments to more complex ones, as follows:

1. Burn several types of solids (e.g., paraffin, nylon, and polyurethane) at various partial pressures of oxygen, using direct and indirect ignition.

2. Burn liquid hydrocarbons, both aromatic and aliphatic species, under the conditions described in item 1 above.

3. Impinge hypergolic fuels and oxidizers (e.g., N_2O_4 and N_2H_4) at various mixture ratios.

4. Burn various metals, using different combustion atmospheres (such as water saturated oxygen).

The instruments necessary to measure the parameters are consistent with the commonality approach taken with the Physics and Chemistry Laboratory. Accelerometers, pressure transducers, cameras (TV or film), optical pyrometers and thermocouples, a mass spectrometer and a timing device to record the experiment sequence are required for this research cluster.

The wide variety of experiments will enable evaluation of the influence of diffusion, flame propagation, interfacial relationships, and the effect of mixing in a near-zero-gravity environment for comparison with similar Earth-based experiments.

4. Impact on Spacecraft.

The power requirements of the research cluster will place minimal demands upon the spacecraft. The experiments are primarily exothermic in nature, and the majority of the power requirements will be from the instrumentation. The experimental facility is the one used for some of the other research clusters in the Physics and Chemistry Laboratory of the Space Station, (e.g., 4-P/C-4). Facility and supporting equipment is approximately 2 ft high, 5 ft wide, and 6 ft long, depending on the configuration. Maximum power is estimated at 1 kw, with an average power level of 0.75 kw during the experimental run. Each experimental run sequence, including setup and refurbishment, will require approximately 30 minutes. The necessary crew skills are reasonably minimal, requiring knowledge of photography and acquaintance with the experimental procedure of the research cluster. Ability to communicate the experimental results to the ground-based scientists, and to observe anomalies that may influence the course of the experimental runs is essential to the success of the research cluster's objectives. The experimental runs will be as automated as possible, since some fire hazards are associated with the experiments. Automatic fire extinguishers and equipment safety interlocks are necessary.

5. Required Supporting Technology Development

Very little supporting research and technology is required to implement this research cluster, except for the design and development of the experimental facility. Since the facility and a majority of the supporting equipment are common to a number of the research clusters of the Physics and Chemistry Laboratory, the commonality aspect of the equipment should be emphasized during the development phase. For this research cluster, in

particular, the pertinent experiments that have already been performed should be reviewed to capitalize on the effort that has already been expended in this area.

6. References

1. Space Processing and Manufacturing. NASA Report No. N-70-14651, NASA MSFC, October 21, 1969.

2. S. Kumagai and H. Isoda. Combustion of Fuel Droplets in a Falling Chamber. Proceedings of the Sixth International Symposium on Combustion, Reinhold Publishing Co., 1956.

3. A. L. Hall. Observations on the Burning of a Candle at Zero Gravity. Bureau of Medicine and Surgery Project MR005.13-1002, Subtask II, Research Report No. 5, U.S. Naval School of Aviation Medicine, Pensacola, Florida, February 26, 1964.

4. J.H. Kimsey, et al. Flammability in Zero-Gravity Environment. NASA TR R-246, 1966.

5. J.H. Kimsey. Experiment Implementation Plan for Manned Space Flight Experiments - Zero Gravity Flammability, Experiment M-479. August 8, 1969.

Critical Issues Addressed by Research Cluster

4-P/C-1
EFFECT OF THE SPACE ENVIRONMENT
ON CHEMICAL REACTIONS

4.1.3.1.1.2.3.1
How is the chemistry of flames and combustion process influenced by a gravity field?

4.1.3.2.1.1
What is the behavior of chemical reactions in the absence of gravity? Are there any effects?

Table 1.
CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
4-P/C-1 -1	Prepare Specimen		3	None		19-B	1	See Note	1	See Note		
-2	Position Specimen in flame holder	Chamber Fixture	5	"		19-B	1	"	1			
-3	Place holder in chamber	Combustion Chamber	5	"		19-B	1	"	1			
-4	Provide combustion atmosphere at desired pressure	Pressure Sensors	5	"		19-B	1	"	1			
-5	Ignite Specimen		5	"	X	19-B	1	"	1			
-6	Make Pyrometric Observations During Combustion	Optical Pyrometer	7	"	X	19-B	1	"	1			
-7	Record combustion process on film	Camera	8	"		19-B	1	"	1			
-8	Make measurements of pressure changes with time	Pressure Recording	8	"		19-B	1	"	1			
-9	Measure flame front or combustion profile	Calibrated Chamber Interior	7	"	X	19-B	1	"	1			
-10	Measure variation of reaction products	Gas Chromatagraph	8	"		19-B	1	"	1			
-11	Make spectral recording	Mass Spectrometer	8	"		19-B	1	"	1			
-12	Remove specimen & products from chamber without contaminating EC/LS system.		5	"	X	19-C	1	"	1			
-13	Clean chamber		4	"		19-C	1	"	1			
-14	Process specimen		8	"		19-C	1	"	1			

†See Legend of Codes, next page. ‡ X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.
Note: Tasks are for each of four (4) experiments. Sixty minutes are required to perform each experiment.

LEGEND OF CODES USED IN CREW ACTIVITY MATRIX

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS—SPACE PHYSICS

4-P/C-2
Shape and Stability of Liquid-Vapor Interfaces

1. Research Objectives

The main objective of this research is to obtain data that describe the nature and degree of liquid-vapor interface instability of fluids under various low-gravity conditions. These data shall apply to both noncryogenic and cryogenic fluids, whose thermodynamic aspects can be studied, using mild cryogenic liquid simulants in the facility described below. This research cluster is also concerned with important basic gravity-dependent fluid phenomena, whose investigation is essential for the design of next-generation spacecraft life support and propulsion systems, as well as future space processing and manufacturing techniques that make use of fluids (such as molten metals and alloys).

2. Background and Current Status

The phenomena, grouped by the similarity of required experimental apparatus (which will be discussed herein) are reorientation flow, sloshing, gas venting, gas pressurization, tank draining, tank filling, and the shape of rotating liquid globules. The linear analyses of liquid surface motion during filling and draining of moving tanks in low-g have been successfully performed. Simple models of axisymmetric reorientation flow have been partially confirmed by drop-tower tests, although the more important nonlinear effects of geyser decay and bubble entrainment have not been observable because the low-g time available during drop tower tests is of short duration. Correlation parameters have been identified for liquid surface deformation during gas venting and pressurization and have been verified by limited tests in the Earth's gravitation field. Extension of existing theories to include large-amplitude asymmetric configurations are extremely difficult. In any case, long-term low-g experimental data are required to confirm analytic predictions and to provide basic design information for the next generation of spacecraft life-support and propulsion systems.

3. Description of Research

Experiments described in connection with this cluster concern themselves with the gravity dependence of the following phenomena: (1) static liquid-vapor interface shape, (2) reorientation flow in a tank following initiation of tank accelerations of various amplitude-time signatures, (3) the sloshing response of liquids to periodic and aperiodic tank loadings, (4) liquid-vapor interface dynamics during space-venting and tank-pressurization operations, (5) liquid vapor interface dynamics during various tank inflow and outflow conditions, and (6) surface shape and stability of rotation liquid drops. Study of these phenomena using the experimental facility described here will provide data and experience that can be

directly applied to the design of space processes in involving noncryogenic fluids as well as to the design of orbital experiments involving cryogenic liquids. The thermodynamic effects of low-g liquid-vapor interface behavior can be studied in the present facility using mild cryogenic simulants. Reasonably simple modifications in the facility could be performed to allow for the testing of the actual hard cryogens, such as LOS, LH_2, and OF_2, which are of interest for life support and propulsion systems.

The intent of the experimental facility described here is to provide maximum visual information concerning the liquid surface behavior under long-term low-g environments, by the use of transparent tanks. The tanks are constructed in such a way that the effects of various mechanical devices (baffles, pressurization gas nozzles) can be studied by having the astronaut partially disassemble a given tank, and insert the device of interest. The use of fully transparent tanks dictates the use of a referee fluid to simulate the hard cryogens (e.g., hexane to simulate LH_2). Also, with information gained about the liquid dynamics during these tests, a test tank with high-performance insulation could be easily added to allow for the testing of actual hard cryogens of interest. Support equipment which is provided for the series of tests will allow the test tank to be exposed to a wide variety of vibrations and gravity levels (10^{-3} to 10^{-6} g). The major part of the data will be taken with cameras having film speeds of 30 and 400 frames per second. These data, together with an amplitude-time base record of vibration, acceleration, valve actuation, and other parameters will comprise the total data package required by the principal investigator on Earth.

4. Impact on Spacecraft

To successfully complete the experiments in this cluster, the crew must carefully perform several tasks. The experiment requires the crew to insert appropriate baffles and hardware inside the test tanks, initiate the tests, and terminate the test and film coverage at an optimal time based on visual observation of the liquid surface. One-half of the test tank must be removed manually, after which alternate test fixtures and baffles shall be installed. In addition, the crew shall be required to close valves and terminate sloshing and rotational movements for the various motions.

An average of 400 w of power is required. The tank equipment must be changed after 2 hours of testing, which will require 1/4 man-hour. The frequency and time duration for the remaining tests will vary but should average once every 1/3 hr and require 1/6 man-hour. One crewman who is acquainted with the experimental sequence and phenomena, as determined by ground testing, is required for each test.

5. Required Supporting Technology Development

The Earth orbital experimental facility for this research cluster must be completely tested on Earth. This is necessary both to establish 1-g results for later comparison with low-g results and to acquaint the astronaut with the experimental behavior so that he can take actions necessary for the progress of the experiment based on his real-time observations. Other activities necessary for the successful deployment and utilization of the Earth orbital facility include (1) development of an accurate low-g accelerometer capable of operating in the 10^{-6} g range, and (2) development of low-g shock and vibration mounts to isolate the experiment platform from spacecraft disturbances. Once deployed, this Earth orbital experimental facility would provide the vital information needed for the design and qualification of the next-generation space fluid systems and components.

6. References

1. H.N. Abramson, The Dynamic Behavior of Liquids in Moving Containers. NASA SP-106, 1966.

2. R.S. Brodkey, The Phenomena of Fluid Motions, Addison-Wesley, Reading, Massachusetts, 1967.

3. S. Chandrasekhar, Hydrodynamic and Hydromagnetic Stability. Oxford, London, 1961.

4. J.O. Fredrickson and J.D. Schweikle. Thermo and Hydrodynamic Experiment Research Module in Orbit. Project Thermo Final Report, DAC-60594, March 1967.

Critical Issues Addressed by Research Cluster

4-P/C-2
SHAPE AND STABILITY OF LIQUID-VAPOR INTERFACES

4.1.3.1.2.1.2.1
What are the thermodynamic properties and density profiles of liquids in the critical region under zero-G conditions?

4.1.3.1.2.1.2.2
How do liquid-vapor interfaces behave in reduced gravity as a function of time?

4.1.4.2.1.1.1
What is the equilibrium configuration of a rotating liquid as a function of gravitational field?

4.1.4.2.1.1.3
What are the oscillatory relaxation times of liquids in zero-G as function of mass and material properties?

4.1.4.2.1.1.4
What are the oscillation periods and shapes of free liquid drops and globules in zero-G/

4.1.4.2.1.1.5
What configurations do liquids assume under zero-G in specific containers?

4.1.4.2.3.2.1
What are the characteristics of vortices in a zero-G environment?

4.1.4.2.3.4.2
How do free liquid droplets interact?

4.1.4.3.2.1
What are surface-wave propagation characteristics of liquids in a zero-G environment?

4.1.4.3.2.2
What is the significance of Rayleigh instabilities in zero-G?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
4-P/C-2												
-1	Install baffles in test tanks	Transparant tanks & baffles	3	None		7-B	8	10	1	See Note		
-2	Checkout Instrumentation	Hot wire flowmeter, camera, accelerometers, liquid drop rotating apparatus	3	"		7-B	8	10	1			
-3	Load Camera		3	"		7-B	8	10	1			
-4	Connect Proper Liquid Sources	Valves, Plumbing	3	"		7-B	8	10	1			
-5	Initiate Experiment, Start Camera		5	"	X	7-B	8	10	1			
-6	Monitor Events		5	"	X	7-B	8	10-45	1			
-7	Adjust Valve openings, rotational speeds, and vibration and impulsive loads.	Accelerometers	5	"	X	7-B	8	10	1			
-8	Terminate where appropriate (stop camera) or initiate subsequent events		5	"	X	7-B	8	10-45	1			
-9	Empty & clean tanks		4	"		7-B	8	15	1			
	NOTE: Tasks are similar for each of five experiments											

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

LEGEND OF CODES USED IN CREW ACTIVITY MATRIX

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS—SPACE PHYSICS

4-P/C-3
Boiling and Convective Heat Transfer in Zero-G

1. Research Objectives

The objective of the subject research cluster is to determine the effect of the gravity level on incipient and nucleate boiling and convective heat transfer. In particular, the onset of convection and nucleate boiling and the vapor bubble generation, growth, velocities, and trajectories will be observed in a low-g environment. These data are required to develop a more comprehensive boiling theory and will also be of value in the design of next-generation space propulsion and life support systems.

2. Background and Current Status

There are theories, confirmed by extensive 1-g testing, that adequately describe free and forced convection. No known data are available regarding this important transport mechanism in low-g environments. There is no comprehensive boiling theory that accounts for the effects of gravity. Limited drop-tower and low-g aircraft tests have been conducted, but the time of observation is much too short to be of use in spacecraft heat transfer design calculations or the formulation of a universal boiling theory. No tests have yet been performed that deal with boiling and convection from a vertical wall in low-g, a very important phenomenon in spacecraft system design.

3. Description of Research

Orbital experiments to provide the required low-g convection and boiling data will be conducted in a closed chamber filled with the test fluid and containing visual observation ports. Primary data will consist of the filmed history of bubble formation, growth, and detachment from various heaters as a function of heat flux, temperature difference, and orientation with the local gravity vector. Various fluids, including the hard liquid cryogens of nitrogen and hydrogen, can be utilized in the tests. Various heater materials and configurations (horizontal, vertical, and curved surface) will provide valuable design data. Temperature measurements at various locations in the liquid will provide information concerning convection currents and their initiation.

The test will be conducted in a 3- by 6-ft insulated tank containing LH_2 and heater surfaces of various types and orientation (horizontal and vertical). Temperatures of the various heater surfaces and the bulk liquid taken at different locations in the tank will be used to determine the heat transfer under convection and boiling conditions. Of particular interest is the point of incipient boiling, nucleate boiling, peak heat flux, and film boiling behavior.

The parameters involved are gravity level and orientation, heater surface condition, surface geometry, pressure, temperature (bulk liquid and heater surface), heater power, and bubble dynamics. Current state-of-the-art instruments, except the low-g gravimeter, can be used to measure all parameters. The astronauts must monitor the tests, activate the cameras and other data-recording equipment, and terminate the tests at the appropriate times.

4. Impact on Spacecraft

An astronaut will be required to activate the heater, monitor tank temperature and pressure, determine when steady state is reached, activate cameras, and readjust the heater. The equipment must be activated by the astronaut, depending on his observations of the activity in the test tank and equipment output readings. An average of 30 w of power is required. Each experimental run sequence, including setup and monitoring, will require approximately 30 minutes. The necessary crew skills are reasonably minimal, requiring knowledge of photography and acquaintance with the test procedures.

5. Required Supporting Technology Development

The experimental facility will be assembled and tested in a 1-g environment, both to establish 1-g data for later comparison with low-g test data and to train the astronauts in the experimental procedure. The development of an accurate low-g accelerometer capable of operating in the 10^{-6} g range will be necessary for the successful deployment and utilization of the Earth orbital facility. With this development, the low-gravity boiling and convective heat transfer test facility described above will possess the versatility and extensiveness to generate required data concerning these transport processes in a variety of test fluid and heat configurations.

6. References

1. J. O. Fredrickson and J. D. Schweikle. Thermo and Hydrodynamic Experiment Research Module in Orbit. Project Thermo Final Report, DAC-60594, March 1967.

2. E. M. Greitzer. Film Boiling on Vertical Surfaces. Technical Report No. 1, Division of Engineering and Applied Physics, Harvard University, June 1969.

3. N. Zuber. Hydrodynamic Aspects of Boiling Heat Transfer. AEC-4439, Department of Engineering, University of California, Los Angeles, 1960.

4. N. Zuber and M. Tribus. Further Remarks on the Stability of Boiling Heat Transfer. AEC-3631, 1958.

Critical Issues Addressed by Research Cluster

4-P/C-3
BOILING AND CONVECTIVE HEAT TRANSFER IN ZERO-G

4\. 1. 3. 1. 2. 1. 2. 3
What are the characteristics of boiling and condensation in zero-G?

4\. 1. 3. 1. 2. 1. 2. 4
What parameters characterize heat transfer in nucleate boiling?

4\. 1. 3. 1. 4. 3. 2
How are free and forced convection influenced by zero-G?

4\. 1. 3. 1. 4. 3. 3
How is boiling heat transfer influenced by zero-G?

4\. 1. 4. 2. 3. 5. 1
How do bubbles move in a zero-G environment, and what are the acting forces?

4\. 1. 4. 2. 3. 5. 2
How do bubbles grow in zero-G, and what are their oscillation characteristics in a convection-free environment?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
4-P/C-3												
-1	Checkout Instrumentation		4	None		7-B	1	*	1	TASKS ARE SAME FOR EACH OF FIVE EXPERIMENTS		
-2	Establish Temperature and Pressure Equilibrium	Sensors	3	"		7-B	1		1			
-3	Activate Heater, Camera, and Data Recording Equipment	Camera Recorder	5/8	"		7-B	1		1			
-4	Observe Liquid Motion (or lack of it) and readouts for stabilization	Tank	5	"	X	7-B	As Req'd		1			
-5	Adjust Heater Current & Gravity Levels	Ammeter Low-G Accelerometers	5	"	X	7-B	1		1			
-6	Terminate Test		5	"		7-B	1		1			
	*REFERS TO NASA REPORT CR 85271											

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

LEGEND OF CODES USED IN CREW ACTIVITY MATRIX

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS--SPACE PHYSICS

4-P/C-4
Effect of Zero-Gravity on the Production of Controlled-Density Materials

1. Research Objectives

This research cluster is identified within the broad category of the NASA-defined Scientific and Technological Objectives in Space Physics for exploiting the unique characteristics of space to conduct experiments not feasible on Earth, by specifically conducting studies in physics and chemistry in the space laboratory.

The scope of this research cluster is to utilize the dominating surface tension effects in a near-zero-gravity environment to produce materials having controlled-density characteristics. Specifically, by mixing materials (of which at least one is in a liquid state) into a stabilized configuration, foams or composites having uniform densities can be produced. Subsequent processing of these materials by reheating and subjecting them to an accelerative force can then produce materials having controlled-density characteristics. Utilizing the near-zero-gravity environment during the initial processing may produce materials having physical characteristics such as strength-to-weight ratios, superior to those obtainable on Earth.

2. Background and Current Status

Production of foamed metals and glasses, and some controlled-density coatings are now being produced on Earth.* Composite materials having a reasonable degree of uniformity are also being produced. These composites usually contain filaments as the reinforcing material, although the greatest increase in strength is obtained by the use of single crystal whiskers. Production of composites containing single crystal whiskers as the reinforcing element, however, has been hampered by the difficulty in incorporating them into the matrix in a uniform manner. Limited data are available on specific tensile and modulus parameters for composite and foamed materials. Theories of the physical behavior of composites are adequate. Further understanding of low-gravity liquid-vapor and liquid-liquid mixing, and interaction phenomena, particularly during solidification,

*Two methods are presently being used to produce foamed materials: sintering of compacted powders, or introduction of gas or gas-forming materials into the melt. The sintering process is limited in the degree of porosity that can be achieved while maintaining adequate physical properties. Introduction of gas or gas-forming materials is limited to relatively low-density and low-melting materials because of gravity separation, although foamed stainless steel is presently available.

is necessary. The necessary data depend upon obtaining experimental material from low-gravity processing of foams and composites.

3. Description of Research

This research cluster is concerned with the production of foamed materials and composites. In each case, the formed products will consist of materials with both uniform and controlled-density characteristics. The experimental approach consists of two sequential steps for each type of material. For the production of foams, the molten material is either extruded through a gas sparger or ultrasonically excited to disperse the gas. This produces foams of uniform density. A portion of the foamed material is then heated and centrifuged to give a triaxially variable density foam. The production of composites is accomplished by heating the matrix-whisker or immiscible metal combination in a shaker and intimately mixing the components in the liquid state. Again, by reheating and centrifuging, triaxially variable density composites may be formed. Foams and composites having controlled, uniaxial density variation can be made on Earth from space-processed samples.

The parameters to be measured during the processing are temperature, pressure, acceleration levels during the initial processing, acceleration levels used in producing the variable-density materials, and total processing time. Depending on the ancillary equipment available, the metallurgical and physical properties of the foams and composites should be determined to correlate the materials with the process parameters.

The instrumentation necessary to measure the parameters are common to the other research clusters and include accelerometers, pressure transducers, cameras (TV or film), optical pyrometers and thermocouples, and a timing device to record the experiment sequence. Ancillary equipment to measure the properties of the materials would include a microscope, sample preparation equipment, and a tensile tester.

4. Impact on Spacecraft

The experimental facility is the one used for some of the other research clusters in the Physics and Chemistry Laboratory, with interior equipment for processing the foams and composites. Facility and supporting equipment is approximately 2 ft high, 5 ft wide, and 6 ft long, depending on configuration. Maximum power is estimated to be 18 kw, with an average power level of 4 kw. Since the processes involve heating and cooling, the heat rejection from the experiments will be a major impact on the space vehicle. Each experimental run, including setup and refurbishment, is estimated to take approximately 1 hour. The necessary crew skills depend on the degree of examination required for the finished materials. The technique of metallographic preparation and examination should be available.

Photographic skills and a clear understanding of the experimental procedure are also necessary. The ability to communicate the experimental results to the ground-based scientists, and to observe process variations is essential. The processes will be as automated as possible, since they entail high temperatures and pressures. Automatic equipment safety interlocks and molten-metal restraint shields are necessary.

5. Required Supporting Technology Development

In addition to the design and development of the basic experiment facility, supporting research and technology required for the processing equipment. The foaming apparatus, power supplies (if induction heating is used), and heat-rejection system must be designed for lighter weight, greater efficiency, and smaller dimensions. A potentially useful concept for thermal management would be to use heat pipes as a passive means to transfer thermal energy from a source to a sink. Also, since the heat pipe can transform the thermal energy in terms of heat flux per unit area, (i. e., from a low flux to a higher one), it may be possible to design the process equipment so that, with a low-heat-flux source, a heat pipe can reconcentrate the heat flux to the equipment to provide additional thermal energy and consequently lower the power demand on the space vehicle.

6. References

1. Space Processing and Manufacturing. NASA Report No. N-70-14651, NASA MSFC, October 21, 1969.

2. Processes for Space Manufacturing, Report No. GDC-DB670-001, NASA Contract No. NAS 8-24979, June 1970.

3. L. Holliday, ed. Composite Materials. Elsevier Publishing Co., New York, 1966.

4. Fiber Composite Materials. ASTM Seminar, Oct 17-18, 1964, ASTM, Metals Park, Ohio, 1965.

5. Composite Materials: Testing and Design. ASTM Special Technical Publication 460, ASTM, Philadelphia, Pennsylvania, 1969.

Critical Issues Addressed by Research Cluster

4-P/C-4
EFFECT OF ZERO-GRAVITY ON THE PRODUCTION OF CONTROLLED DENSITY MATERIALS

4.1.4.2.3.3.1
How can structures of uniform density of suspended materials be achieved in a zero-G environment?

4.1.4.2.3.3.2
Can the space environment be effectively used to achieve castings with specific density distributions?

4.1.4.2.3.3.4
How can the space environment be used for controlled density casting?

4.1.4.2.3.4.1
How does liquid mixing in a gravity-free environment differ from that expected in a 1-G environment?

4.1.4.2.3.5.3
Is it feasible to produce foam of glassy materials of uniform density in space?

4.1.5.4.2.1.3
Is it feasible to produce metal foam of uniform density in space?

Table I

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY +	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL +	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START +	DURATION +	TASK CONCURRENCY +
4-P/C-4												
-1	Checkout Instrumentation		4	None		7-B	At least 1	12	1			EXPERIMENT DUPLICATED IN ONE-G
-2	Sample Placement	Chamber	3			7-B	"	6	1			
-3	Position Sensors	Sensors	3			7-B	"	6	1	TASKS EACH	ARE SAME FOR OF SIX	EXPERIMENTS
-4	Adjust Atmosphere and Pressure	Controls	3			7-B	"	12	1			
-5	Initiate Data Acquisition	Camera and Recording Equip.	8			7-B	"	6	1			
-6	Initiate Experiment		5		X	7-B	"	6	1			
-7	Manually Control Power and Pressure if necessary	Gas Sparger	5		X	7-B	"	30	1			
		Shaker										
-8	Visually Monitor Temperature and Pressure		5		X	7-B	"	30	1			
-9	Terminate Experiment		5			7-B	"	12	1			

C-4-2

+See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

LEGEND OF CODES USED IN CREW ACTIVITY MATRIX

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS – SPACE PHYSICS

4-P/C-5
Effect of Electric and Magnetic Fields on Materials

1. Research Objective

This research cluster is identified within the broad category of the NASA-defined Scientific and Technological Objectives in Space Physics for exploiting the unique characteristics of space to conduct experiments not feasible on Earth. by specifically conducting studies in physics and chemistry in a space laboratory.

The scope of this research cluster is to establish the effects of a near-zero-gravity environment on the behavior of materials in the presence of electric or magnetic fields. Specifically, the changes in the heat-transfer characteristics of a liquid and liquid-vapor transport as a function of nonlinear electric or magnetic field strength will be investigated. Other material-electromagnetic field interactions could be investigated in a near-zero-gravity environment, but the applicability of these experiments has not been established with respect to the pertinent NASA objectives. Investigation of the heat transfer and transport phenomena in an Earth orbital experimental facility, and comparison of the results with those determined on earth, should provide data for a comprehensive understanding of the use of nonlinear electromagnetic interactions in the design of future Space Station life support and propulsion utilization systems.

2. Background and Current Status

Prototype models have been designed and built, utilizing nonlinear electric and magnetic fields for orientation of liquid oxygen with respect to using its vapor to prevent liquid-vapor agglomeration during vapor or liquid transfer. Modeling experiments have been performed, using nonlinear electric fields to increase the heat-transfer coefficient of dielectric fluids in the regime of natural convection and to increase the heat flux in both the nucleate and film-boiling regimes. The use of magnetic fields to enhance heat-pipe performance also has been proposed. Analyses of the effect of nonlinear electromagnetic fields on liquid-vapor separation and heat transfer in a near-zero-gravity environment have been successfully performed. Limited drop-tower and low-g aircraft tests have partially confirmed the predicted behavior of fluids under these conditions, but the time of observation was too short to obtain complete confirmation in an equilibrium situation. Thus, long-term experimental data in a near-zero-gravity environment are required to confirm the analytic calculations and to provide design information for future Space Station life support and propulsion utilization systems.

3. Description of Research

This research cluster is concerned with the use of nonuniform electromagnetic fields to orient liquid-vapor interfaces and to enhance the heat-transfer coefficient and heat flux of liquids in the nucleate and film-boiling regimes. The experimental approach consists of sequential tests utilizing nonlinear electric or magnetic fields. For the nonuniform electric field tests, the fluid is introduced into a cylindrical tank containing a center heater with a cylindrical wire-mesh screen concentric to the heater. A thermal gradient is imposed across the liquid, and a nonuniform electric field is applied between the heater and the screen. The heat flux at the nucleate and film-boiling points and the liquid-vapor interface will be measured as a function of the electric field intensity imposed across the liquid. The experiment will be repeated with no electric field imposed as a reference point. In the case of the nonuniform magnetic field tests, the fluid is introduced into a cylindrical tank containing a center heater with a flat, annular electromagnet at the bottom of the tank. A thermal gradient is imposed across the liquid, and a nonuniform magnetic field is applied radially from the center of the tank to the outside wall. The heat flux at the nucleate and film-boiling points and at the liquid-vapor interface will be measured as a function of the magnetic field intensity imposed across the liquid. The experiment will be repeated with no magnetic field imposed as a reference point.

The parameters to be measured during the experiments are temperatures, thermal input to the fluid, electric and magnetic field intensities, shape and orientation of the liquid-vapor interfaces, acceleration levels during the experimental runs, and total experiment time.

The instruments necessary to measure the parameters include accelerometers, cameras (TV or film), thermocouples, voltmeters and ammeters, a gauss meter, and a timing device to record the experiment sequence.

4. Impact on Spacecraft

The experimental facility can be the same one utilized for some of the other research clusters in the Physics and Chemistry Laboratory, with provisions for securing the experiment tanks on the inside. The facility and supporting equipment are approximately 2 ft high, 5 ft wide, and 6 ft long, depending on configuration. Maximum power is estimated to be 2 kw, with an average power level of 200 w. Since the experiments involve the use of cryogenic liquids in some instances, the major impact on the space vehicle will be the need of adequate thermal insulation of the experiment tanks and containment of the liquid if a leak occurs. The experiments will be as automated as possible, with automatic equipment interlocks and overboard dumping provisions. Each experimental run, including initial isothermalization and refurbishment, is estimated to take 2 hr. Crew participation time per run is estimated to be 1 hr.

Photographic skills and a clear understanding of the experimental procedure are necessary. The ability to communicate the experimental results to the ground-based scientists, and to observe variations during the experiment run is essential. These skills can be acquired by prototype ground testing.

5. Required Supporting Technology Development.
In addition to the design and development of the basic experiment facility and test equipment, testing of the facility on Earth must be performed for 1-g and low-g comparison. Development of thermal insulation and low-g isolation shock and vibration mounts for the experiment tanks is also necessary.

6. References

1. J. Bitten. Liquid Oxygen Converter. WADD Technical Report No. 60-669, Contract No. AF 33(616)-6756, January 1961.

2. J. M. Reynolds, III, et al. Design Study of a Liquid Oxygen Converter for use in Weightless Environments. Technical Report No. AMRL-TDR-63-42, Contract No. AF 33(657)-9423, June 1963.

3. M. Winer. An Experimental Study of the Influence of a Non-uniform Electric Field on Heat Transfer in a Dielectric Fluid. TRW Report No. 99900-6315-R0-99, August 1967.

4. R. L. Johnson. Effect of an Electric Field on Boiling Heat Transfer. AIAA Journal 6, 1968, P. 1456.

5. G. A. Carlson and M. A. Hoffman. Effect of Magnetic Fields on Heat Pipes, Paper No. 70-HT/SpT-10, presented at the Space Technology and Heat Transfer Conference, ASME, Los Angeles, California, June 21-24, 1970.

Critical Issues Addressed by Research Cluster

4-P/C-5
EFFECT OF ELECTRIC AND MAGNETIC FIELDS ON MATERIALS

4.1.3.3.1.2.1
How are phase-change phenomena affected by the presence of electric and magnetic fields in low- and zero-g environment? Can such fields be used for controlling phase changes?

4.1.4.2.1.1.6
How does the presence of electric and magnetic fields affect the dynamic and static behavior of dielectric and conducting liquids in zero- or low-gravity environment?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
4-P/C-5 -1	Checkout Instrumentation		4	None		19-B	* SEVERAL MATERIALS WILL BE TESTED, IN EACH OF TWO ALTERNATIVES		1			DUPLICATE IN ONE-G ENVIRONMENT
-2	Place Test Material in Chamber	Chamber	3	"		7-B		60	1			
-3	Prepare Chamber Environment	Valves Plumbing	3	"		7-B		60	1			
-4	Position Sensors	Sensors	3	"		19-B		60	1			
-5	Initiate Camera and Data Recording	Camera and Recorders	8	"		19-B		60	1			
-6	Initiate Test by Application of Heat and Applicable Electrostatic or Magnetic Field	Heaters and Field Elements	5	"		7-B		60	1			
-7	Monitor Test Material Temperature of Molten or Boiling state.	Sensors	5	"	X	7-A		60	1			
-8	Monitor Property Changes and Heat Transfer Rates	Densitometer Viscometer	5	"	X	7-A		60	1			
-9	Repeat Cycle with Field Variations	Same as 6.	5	"	X	7-A		60	1			
-10	Calibrate Resistance Thermometers	Thermometer	4	"		19-B		60	1			
-11	Terminate Test		5	"	X	7-A		60	1			
-12	Evaluate Data For Comparison with control experiments on Earth.		6	"		7-A		60	1			
-13	Clean Test Chamber		4	"		0-C		60	1			

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.
Estimate: Two types of fields, three levels each, six materials = 36 tests.

LEGEND OF CODES USED IN CREW ACTIVITY MATRIX

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS--SPACE PHYSICS
4-P/C-6
Use of Zero-Gravity to Produce Materials Having Superior Physical Characteristics

1. Research Objectives

This research cluster is identified within the broad category of the NASA-defined Scientific Technological Objectives in Space Physics for exploiting the unique characteristics of space to conduct experiments not feasible on Earth, by specifically conducting studies in physics and chemistry in a space laboratory.

The scope of this research cluster is to utilize the near-zero-gravity environment of a space laboratory to produce glasses, single crystals, and whiskers (microscopic single crystals). The absence of containers, density gradients, weight stresses, or other body forces will reduce or eliminate undesirable nucleation sites, dislocations, or other imperfections normally found in crystals or glasses, which limit their degree of perfection on Earth.

2. Background and Current Status

Currently, many techniques are used to grow crystals and amorphous glasses. The primary techniques used to grow large single crystals are zone refining (Czochralski, Bridgeman-Stockbarger, Bridgeman, Verneuil) and solution or vapor growth. Whiskers are usually grown by direct vapor transport, thermal disassociation of compounds, or surface reaction and preferential nucleation growth. Amorphous glasses are prepared by carefully controlling nucleation by properly choosing containers and thermal processing parameters, by adding nucleation suppressants, and by glass "fining" (repeated thermal stabilization of the liquid phase and selective removal of the clarified portions of the glass).

The theoretical aspects of crystal growth are well known. Comparison of the calculated theoretical physical properties of crystals with their actual properties, however, indicates that the dislocation density of crystals is much higher than would be expected. Since dislocations are not an equilibrium defect, it should be possible to grow perfect crystals on Earth from a melt. In addition to impurities, however, it has been shown that gravity-induced effects, such as thermal convection in the liquid phase, density-gradient differences during solution growth, weight stress, and other body forces present during processing contribute to the formation of dislocations as the crystal is grown.

The current knowledge and theory of the formation of glasses (or amorphous solids) are not as complete as they are for crystals. Knowledge covering the formation and constitution of glasses is largely empirical in nature, although recent investigations have contributed to a better understanding of the principles of glass

formation. Recent investigations of the preparation of glasses and other noncrystalline solids by unusual methods, such as the use of shock waves, rapid cooling from the melt ($>10^6$ degrees C/sec), neutron bombardment, high-pressure melting and vapor deposition on cold substrates, have shown that a wide variety of glasses and other noncrystalline solids may be produced if the long-range ordering forces can be disrupted or if extraneous nucleation can be prevented. These methods are indicative of the advantages of eliminating undesirable nucleation sites, which lend to crystalline imperfections in glass.

Thus, experimental facility must be placed in a near-zero-gravity environment for confirmation of analytic predictions and to obtain materials that are free of gravity-induced imperfections for examination and comparison with Earth-grown materials.

3. Description of Research

This research cluster is concerned with the preparation of large single crystals, whiskers, and glasses, and with determination of the gravity-dependent parameters associated with their production. The approach consists of three separate experimental procedures. Large single crystals will be produced by float zone, or solution growth techniques. Depending on the material to be crystallized, whiskers will be grown by vapor transport, thermal dissociation, or surface reaction and preferential nucleation on a substrate, and glasses will be produced by initial resistance heating of the oxides until the conductivity of the material is sufficient for containerless induction heating.

The parameters to be measured during the processing are temperature, rate of heating and cooling, growth rate when float zone or Czochralski methods are used, pressure, acceleration levels during the processing period, and total processing time. Since gravity-dependent parameters are to be determined also, crystal perfection and the homogeneity and degree of noncrystallinity of the glasses must be measured.

Most of the instruments required to measure the parameters are common to other research clusters in the Physics and Chemistry Laboratory. The common instrumentation includes accelerometers, pressure transducers, cameras (TV or film), optical pyrometers and thermocouples, and a timing device to record the experiment sequence. Ancillary instrumentation consists of position sensors to determine material position, and crystal pull or float zone pass rate. Minimum equipment necessary to determine the properties of the materials and the gravity-dependent parameters includes a microscope, metallographic equipment, a tensile tester, and an x-ray diffraction unit. More comprehensive analyses will be performed on Earth.

4. Impact on Spacecraft

The basic experimental facility is the same one used for some of the other research clusters in the Physics and Chemistry Laboratory, with interior equipment for processing crystals, whiskers, and glasses. Facility and supporting equipment are approximately 2 ft high, 5 ft wide, and 6 ft long, depending on configuration. Maximum power is estimated to be 15 kw, with an average power level of 4 kw. Since the processes involve heating and cooling, the major impact on the spacecraft is the need for heat rejection from the facility, with a secondary requirement for space vacuum blowdown. Depending on the location of the facility with respect to the space vehicle, secondary ion-pump capability may be necessary to achieve the hard vacuums ($<10^{-8}$ torr) required for some of the experiments. The time for experimental runs will depend on the material to be processed. Depending on the degree of homogenization required for glass processing and the type of crystallization techniques used, the experiment time will vary from 5 to 16 hours. Crew participation time, including experiment setup and refurbishment, is estimated to be about 2 hr. The process can be highly automated and requires only periodic attention, once the experimental run is started. The crew will require knowledge of metallographic, optical, and x-ray diffraction techniques to determine the material properties, gravity-dependent parameters, and process anomalies. A clear understanding of the experimental procedures and the ability to communicate the experimental results to ground-based scientists is necessary. These skills can be acquired by prototype ground testing. Since the processes entail high temperatures, automatic equipment safety interlocks and molten-metal or glass restraint shields are necessary.

5. Required Supporting Technology Development

In addition to the design and development of the basic experiment facility, supporting research and technology are required for the processing equipment. The power supplies for electron-beam and induction heating, the position control units, and the heat-rejection system must be designed for lighter weight, greater efficiency, and smaller dimensions. A suggested heat-rejection system was described in research cluster synopsis 4-P/C-4. A position control system is under development on a NASA contract and can be applied to this set of experiments.

6. References

1. Manufacturing Technology Unique to Zero-Gravity Environment. NASA MSFC, November 1, 1968.

2. Processes for Space Manufacturing. NASA Report No. N-70-14651, NASA MSFC, October 21, 1969.

3. L. R. McCreight, H. W. Ranch, Sr., and W. H. Sutton. Ceramic and Graphite Fibers and Whiskers, A Survey of the Technology. Academic Press, New York, 1965.

4. J. J. Gilman, ed. The Art and Science of Growing Crystals. John Wiley and Sons, New York, 1963.

5. J. D. Mackenzie, Ed. Modern Aspects of the Vitreous State, Vols. 1, 2, and 3, Butterworths, Washington, 1960-1964.

6. W. A. Weyl and E. C. Marboe. The Constitution of Glasses - A Dynamic Interpretation, Vol. 1, Interscience Publishers, New York, 1962.

7. Investigation of the Preparation of Materials in Space, Task IV: Field Management for Positioning and Processing of Free Suspended Liquid Materials. Final Report, NASA Contract No. NAS 8-24683, Modification No. 2, Control No. DCN 1-9-20055, S2, May 15, 1970.

Critical Issues Addressed by Research Cluster
4-P/C-6

THE USE OF ZERO-GRAVITY TO PRODUCE MATERIALS HAVING SUPERIOR PHYSICAL CHARACTERISTICS

4.1.4.2.1.1.2
What are the exact shapes and surface properties of free-cast materials?

4.1.4.2.1.2.1
How are free shapes and the properties of melts influenced by cohesion and/or surface tension?

4.1.4.4.1.1.1
Can space be used to improve the quality of glass materials?

4.1.4.4.1.1.2
Can space be used to cast better lenses and glass blanks?

4.1.5.4.1.3.5.1
What are the effects of gravity on solidification and crystal growth out of melts?

4.1.5.4.1.3.5.2
How can these effects be utilized to improve the size, quality, and purity of industrial-quality crystals?

4.1.5.4.1.3.5.3
Is it possible to grow giant single crystals of high perfection?

4.1.5.4.1.3.5.4
How does weight-stress elimination influence the quality of crystals grown out of melts?

4.1.5.4.1.3.5.5
What are the observable dependent parameters effected by gravity?

4.1.5.4.1.3.5.6
What are the potential advantages of zone refining of singe crystal in zero-G?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
4-P/C-6												
-1	Checkout Instrumentation		4	None		19-B	1	12	1	TASKS ARE SAME FOR EACH OF FOUR EXPERIMENTS		
-2	Set-up (Sample & Equipment)	Chamber Accelerometer	3	"		19-B	1	6	1			
-3	Adjust Atmosphere & Pressure	Chromatagraph Mass Spectrometer Pressure Sensor	3	"		19-B	1	12	1			
-4	Position Temperature Sensor	Pyrometer	3	"		19-B	1	6	1			
-5	Initiate Data Acquisition	Recording Equip	8	"		19-B	1	6	1			
-6	Initiate Experiment	Heater	5	"		19-B	1	6	1			
-7	Observe for Possible Override	Controls	5	"	X	19-B	1	60	1			
-8	Terminate Experiment		5	"	X	19-B	1	6	1			
-9	Process Specimen		6	"		19-B	1	6	1			
-10	Clean-up Chamber		4	"		19-B	1	12	1			
-11	Sensor Calibration		4	"		19-B	1	6	1			
-12	Preliminary Data Evaluation		6	"		19-B	1	4	1			

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

LEGEND OF CODES USED IN CREW ACTIVITY MATRIX

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS--SPACE PHYSICS
4-P/C-7
Improvements of Materials by Levitation Melting

1. Research Objectives

This research cluster is identified within the broad category of the NASA-defined Scientific and Technological Objectives in Space Physics for exploiting the unique characteristics of space to conduct experiments not feasible on Earth, by specifically conducting studies in physics and chemistry in a space laboratory.

The scope of this research cluster is to investigate the effect of the space environment on the levitation melting of materials. Specifically, levitation melting will be performed at near-zero-gravity levels, in both inert atmospheres and vacuum. Samples will also be vacuum cast. These experiments will determine whether homogenization, purification, and casting of materials can be improved over the results achievable on earth.

2. Background and Current Status

The development and utilization of levitation melting is extensive, and the method has been used for preparation of very pure metal samples. There are basic limitations on the use of electromagnetic levitation melting, which have restricted its use to small quantities of metal. The technique is also limited to metals because the levitation forces increase with the conductivity of the specimen. There is a limitation to the sample size and type since the levitation forces are applied primarily to the peripheral edges of the specimen and the lower axial fluid is kept in place by the forces of surface tension only. Thus, high-density, low-surface tension metals cannot be levitation-melted at all. Large power requirements (10 to 50 kw) are necessary to levitate even a small (about 10-gram) specimen at 1-g conditions. The interdependence between levitation forces and specimen heating do not allow arbitrary temperature excursions, thus limiting the allowable processing temperatures.

In a near-zero-gravity environment, these restrictions are eased, and large samples or materials with lower electrical conductivity can be levitation melted at lower power levels. In addition, because of density differences, such materials as compound semiconductors can be melted without segregation. Since levitation melting is a containerless operation, subcooling of the specimen is likely to occur, with the potential of producing more perfect crystals due to rapid solidification from a single nucleation site.

Therefore, levitation melting in a near-zero-gravity environment is desirable so that the effect of other parameters, such as temperature, vacuum, and cooling rates on the properties of

materials, can be determined independently. This will provide information on the homogenization, purification, and casting of materials in space and allow a comparison of their properties with those obtainable on earth.

3. Description of Research
This research cluster is concerned with the improvement in the homogeneity and purity of materials, and in the quality of castings. The approach consists of three experimental procedures. The first procedure will consist of the levitation melting of samples in an inert atmosphere and of resolidifying the samples at various specified cooling rates. In the second procedure, the samples will be levitation-melted in a vacuum, held for specified times in the molten state, and resolidified at various cooling rates. The third procedure will be to levitation-melt the samples in a vacuum and hold it for various specified times in the molten state. The molten samples will then be subjected to an acceleration force and cast into molds.

The parameters to be measured during the processing are temperature, rate of cooling, pressure, acceleration levels during the processing period, and total processing time. The degree of homogenization, purification, and quality of casting should also be determined if possible.

Most of the instrumentation necessary to measure the parameters are common to other research clusters in the Physics and Chemistry Laboratory. The common instrumentation includes accelerometers, pressure transducers, cameras (TV or film), optical pyrometers, and a timing device to record the experiment sequence. Ancillary instrumentation consists of a position sensor to determine material position within the levitation melter. The minimum equipment necessary to determine the properties of the processed materials includes a microscope, metallographic equipment, a tensile tester, and an x-ray diffraction unit. A more detailed examination of the materials will be performed on Earth.

4. Impact on Spacecraft
The basic experimental facility is the same one used for some of the other research clusters in the Physics and Chemistry Laboratory, with interior equipment for levitation melting and material casting. The facility and supporting equipment are approximately 2 ft high, 5 ft wide, and 6 ft long, depending on configuration. Maximum power is estimated to be 5 kw, with an average power level of 2 kw. Since the processes involve heating and cooling, the major impact on the spacecraft is the heat rejection from the facility with a secondary requirement for space vacuum blowdown. A secondary ion pump capability may be necessary to achieve the hard vacuums ($<10^{-8}$ torr) required during processing, depending on the location of the

facility with respect to the spacecraft. The processing time per experimental run will vary in accordance with the swell time of the molten mass in vacuum and the cooling rate, and is estimated to be between 1 and 2 hr. The crew participation time including experiment setup and refurbishment, is estimated to take 1 hr. The process will be highly automated and require only periodic attention once an experiment run is started. The experiment runs involving casting of the sample after melting must be monitored during casting to prevent misalignment and release of molten material within the facility. The crew will require knowledge of metallographic, optical, and x-ray diffraction techniques to determine the properties of the processed materials and process anomalies. An understanding of the experimental procedures and the ability to communicate the experimental results to ground-based scientists will be necessary. These skills can be acquired by prototype ground testing. Since the processes involve high temperatures, the experiment runs will be as automated as possible, including equipment safety interlocks and restraint shields against molten material impingement.

5. Required Supporting Technology Development

In addition to the design and development of the basic experiment facility, supporting research and technology are required for the processing equipment. The power supplies for the induction and electron-beam heating, the position control units, and the heat-rejection system must be designed for lighter weight, greater efficiency, and smaller dimensions. A suggested heat-rejection system was described in Research Cluster Synopsis 4-P/C-4. A position-control system under development on a NASA contract can be applied to this set of experiments.

6. References

1. Manufacturing Technology Unique to Zero-Gravity Environment. NASA MSFC, November 1, 1968.

2. Processes for Space Manufacturing. Report No. GDC-DB670-001, NASA Contract No. NAS 8-24979, June 1970.

3. L. R. Weisberg. Review of Scientific Instruments, Vol. 30, 1959, p. 135.

4. Investigation of the Preparation of Materials in Space, Task IV: Field Management for Positioning and Processing of Free Suspended Liquid Materials. Final Report, NASA Control No. NAS 8-24683, Modification No. 2, Control No. DCN 1-9-54-2005, 52, May 15, 1970.

Critical Issues Addressed by Research Cluster
4-P/C-7

IMPROVEMENTS OF MATERIALS BY LEVITATION MELTING

4.1.5.4.2.1.1
How can the process of levitation melting be improved?

4.1.5.4.2.1.4
How can the process of vacuum melting and casting be improved in the space environment?

4.1.5.4.2.2.1.1
How can vacuum and natural levitation in space be used to obtain high-purity materials?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
4-P/C-7												
-1	Set-up chamber with specimen	Chamber	3	None		7-B	1	60	1	TASKS ARE FOR EACH OF FOUR EXPERIMENTS		
-2	Checkout Instrumentation		4	"		19-B	1	60	1			
-3	Establish Environment		3	"		7-B	1	60	1			
-4	Initiate Experiment	* Induction Heater Magnetic Field	5	"		7-B	1	60	1			
-5	Monitor Specimen Position and Temperature during cooling period	Pyrometer	5	"	X	7-B	1	60	1			
-6	Initiate Data Recording	Camera Recorder	8	"		19-B	1	60	1			
-7	Terminate Experiment		5	"		7-B	1	60	1			
-8	Process Specimen		8	"		7-B	1	60	1			

* EQUIPMENT FOR MAGNETIC FIELD TO POSITION SPECIMEN NOT SPECIFIED.

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

LEGEND OF CODES USED IN CREW ACTIVITY MATRIX

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS--SPACE PHYSICS
4-P/C-8
The Effect of Zero-Gravity on the Production of Films and Foils

1. Research Objectives

This research cluster is identified within the broad category of the NASA-defined Scientific and Technological Objectives in Space Physics for exploiting the unique characteristics of space to conduct experiments not feasible on Earth, by specifically conducting studies in physics and chemistry in a space laboratory.

The scope of this research cluster is to produce thin films and foils, both single-layered and multilayered, and to observe surface-tension effects on sputter and vapor-deposition processes and wetting characteristics of materials in a near-zero-gravity environment. The performance of these experiments in an Earth orbital experiment facility, and comparison of the results with those determined on Earth, should provide data for a comprehensive understanding of the effect of a near-zero-gravity environment on the production of thin films and foils.

2. Background and Current Status

The development and utilization of sputter-deposition and vacuum-evaporation techniques for production of thin films on substrates is extensive and has been used for production of a wide variety of products. The sublimation and sputtering behavior, and the nucleation kinetics of thin-film production is understood, although the influence of such variables as purity of materials, sputter gas, substrate surfaces, and residual gas composition of the evaporation vacuum has precluded a comprehensive prediction of thin-film formation. The potential of obtaining high-purity materials from other space processing techniques will be of definite advantage to this research cluster, with respect to high-purity depositions. Foil-production techniques are well known, but they are limited with respect to material, thickness, dimensional tolerance, and size. Surface tension effects are utilized to produce sheet glass and certain organic membranes, but the technique is limited to relatively low-melting-point, nonreactive materials. Adhesion and layer casting techniques are known, but the effect of gravity limits the fabrication of complex shapes.

The utilization of surface tension forces in a low-gravity environment to produce various types of thin films and foils has been extensively investigated, and a large amount of information is available with regard to the theoretical behavior of materials. Near-zero-gravity experiments are required, however, to confirm analytic predictions and to provide materials for evaluation.

3. Description of Research

This research cluster is concerned with the production of thin films and foils, both single-layered and multilayered, and the observation of surface tension effects on the nucleation kinetics, sublimation behavior, and melting characteristics in a near-zero-gravity environment. The approach consists of three separate experimental procedures. Thin films will be deposited by sputter and vapor deposition techniques on various substrates, with an imposed thermal gradient across the substrate surface. Various deposition rates and film thicknesses will be utilized during this experimental sequence. Foils will be produced by extruding molten material through a die slit, touching the extruded material with a cooled knife-edge substrate, and then rapidly withdrawing the edge to form a thin foil. The withdrawal rate of the knife edge will be varied to produce foils of different thicknesses. Adhesion and layer castings will be produced by partially inserting substrates of varying geometries (e. g., tubes, foils, and screens) into a sphere of molten material and observing the wetting characteristics. Various substrate and coating materials will be used.

The parameters to be measured during the processing are temperatures, acceleration levels during the process period, film-deposition rates and thicknesses, foil withdrawal rates and thicknesses, and wetting and sublimation characteristics of the materials being evaporated. Determination of the nucleation behavior and the integrity of the films and foils produced would be desirable, but the time involved and the complexity of the required equipment may require that the processed materials be sent to Earth for detailed examination.

The instrumentation necessary to measure the parameters are accelerometers, pressure transducers, optical pyrometers and thermocouples, cameras (TV or film), a timing device to record the experiment sequence, a crystal film-thickness monitor, and a position sensor to measure the foil-withdrawal rate. The minimum equipment necessary to measure the properties and characteristics of the materials produced includes a microscope, metallographic equipment, an x-ray diffraction unit, a foil thickness gauge, and a surface profilometer.

4. Impact on Spacecraft

The basic experimental facility is the one used for some of the other research clusters in the Physics and Chemistry Laboratory, with interior equipment for processing films, foils, and adhesion and layer castings. The module and supporting equipment are approximately 2 ft high, 5 ft wide, and 6 ft long, depending on configuration. Maximum power is estimated to be 20 kw with an average power level of 5 kw. Since some of the processes involve heating and cooling, the major impact on the space vehicle is the heat rejection from the facility. A secondary requirement is provision for space vacuum blowdown.

An ion pump may be necessary to achieve the hard vacuums ($<10^{-8}$ torr) required during processing, depending on the location of the facility with respect to the spacecraft. The processing time per experimental run will vary in accordance with the deposition time in the formation of films, and is estimated to be between 1 and 2 hr. The crew participation time, including experiment setup and refurbishment, is estimated to take 1 hr. The processes will be highly automated, thus requiring only periodic attention once the experiment run is started. The initiation of the foil production and adhesive casting experiments must be monitored to prevent misalignment and release of molten material within the facility. The crew will require knowledge of metallographic, optical, and x-ray diffraction techniques to determine the properties of any one material and anomalous process variations. A clear understanding of the experimental procedures and the ability to communicate the results to ground-based scientists is necessary. These skills can be acquired by prototype ground testing. Because of the temperatures involved in some of the experiments, automated equipment safety interlocks and restraint shields against molten material impingement will be necessary.

5. Required Supporting Technology Development

In addition to the design and development of the basic experiment facility, supporting research and technology are required for the processing equipment. The power supplies for the sputter-deposition apparatus, and the heat-rejection system must be designed for lighter weight, greater efficiency, and smaller dimensions. A potential heat-rejection system was described in research cluster synopsis 4-P/C-4. The foil production apparatus, although conceptual at present, is based on metal and plastic extruders, with the inclusion of the knife edge to produce thinner foils. Therefore, this device must also be developed.

6. References

1. J. J. Gilman, ed. The Art and Science of Growing Crystals. John Wiley and Sons, Inc., New York, 1963.

2. Thin Films. Siminar of the American Society for Metals. October 19 and 20, 1963, ASTM, Metals Part, Ohio, 1964.

3. L. Holland. Vacuum Deposition of Thin Films. John Wiley and Sons, Inc., New York, 1958.

4. G. Hass and R. E. Thor, eds. Physics of Thin Films, Vols. 1, 2, and 3 Academic Press, New York, 1963, 1964, and 1966.

5. Manufacturing Technology Unique to Zero-Gravity Environment. NASA MSFC, November 1, 1968.

6. Space Processing and Manufacturing. NASA Report No. N-70-14651, NASA MSFC, October 21, 1969.

7. Processes for Space Manufacturing. Report No. GDC-DB670-001, NASA Contract No. NAS 8-24979, June 1970.

Critical Issues Addressed by Research Cluster
4-P/C-8
EFFECT OF ZERO-GRAVITY ON THE PRODUCTION OF FILMS AND FOILS

4.1.3.1.2.1.3.1
How do metals sublime and condense in zero-G?

4.1.4.2.3.3.3
How is the process of adhesion or layer casting influenced by zero-G, and what are the resulting material properties?

4.1.5.4.2.2.3.1
Is the space environment an effective medium for generating thin films by use of sputtering or evaporation techniques?

4.1.5.4.2.2.3.2
Is the space environment an effective medium for surface deposition and surface-tension drawing of thin films?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START †	DURATION †	TASK CONCURRENCY †
4-P/C-8												
-1	Set-up Test Apparatus	Chamber	3	None		19-B	**	60	1			
-2	Checkout Instrumentation		4	"		19-B		60	1	TASKS ARE FOR EACH OF THREE SEPARATE EXPERIMENTAL PROCEDURES		
-3	Establish Atmosphere		5	"		19-B		60	1			
-4	Position Sensors (Temp, pressure, humidity, thickness, current, voltage, position and motion)	Sensors	3	"		19-B		60	1			
-5	Initiate Experiment *	Deposition Apparatus & Heat Source	5	"	X	7-B		180	1			
-6	Monitor and Adjust Position and Motion	Controls	5	"	X	7-B		180	1			
-7	Observe Film Growth and Thickness		5	"	X	7-B		180	1			
-8	Complete Test		5	"	X	7-B		180	1			
-9	Clean-up		4	"		0-C		180	1			
-10	Process Specimen		8	"		7-B		180	1			
	*No sensor recording requirement.											

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.
**Estimate: Five thicknesses, five tests ≈ frequency of 25.

LEGEND OF CODES USED IN CREW ACTIVITY MATRIX

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS--SPACE PHYSICS

4-P/C-9

Effects of Zero-G on Liquid Releases and Liquid Drop Size Distribution

1. Research Objectives

The main objective of this research is to study liquid-gas interfaces and the behavior of liquid dispersions in a zero-gravity environment. The behavior of liquid globules shall be investigated by rotating them at various speeds in zero gravity. A further objective is to advance the state of knowledge in the basic behavior of fluids under zero-gravity conditions in support of future fluid system design and development.

2. Background and Current Status

Droplet size distributions under Earth gravity (1-g) conditions in air streams have been investigated in detail. The behavior of droplets in zero-g has also been observed in free-falling tubes containing mercury. More knowledge is required about the interaction of droplets and the shapes and oscillations occurring in larger droplets. The Kelvin-Helmholtz instability in simple geometries is understood, but the influence of gravity on this phenomenon is not well understood. This type of research also has great impact on the understanding of the physical phenomena of clouds.

3. Description of Research

The important parameters to be measured are size distribution of liquid droplets, spray velocity, shape of droplets, spatial distribution, drop oscillation frequency, and damping constant. Air or another suitable gas is made to flow at various velocities over liquid films of various thicknesses. The gas stream is then passed through an aerosol counter to determine droplet size distribution. Water-saturated air is passed over a condensing surface, and the motion of the condensate and the liquid droplet size distributions are observed downstream of the condensation plate. Drop oscillation frequencies, shapes, and attenuation rates are determined by high-speed photography.

A plexiglass tank is equipped with a diffuser to determine the onset of Kelvin-Helmholtz instabilities. The chamber is illuminated for filming the inflowing dispersing liquid. The onset of instability will be observable, along with the entrainment of gas into the dispersing liquid. Measurements must be taken of the liquid flow rates. An alternate approach would be to let an axial gas stream impinge on a liquid surface to observe the onset of instability and liquid cavitation. A grid system placed inside the chamber would be used to determine the surface deformation caused by the gas flow.

To study rotating liquid globules, a transparent, spherical tank is required. The chamber is equipped with a rotating capillary tube, on the end of which the behavior of a rotating liquid globule can be studied. High-speed photography and external lighting must be used. Pressure gages in the tank and feedlines and equipment for monitoring motor power and drive speed are also required. In addition accurate gravity vector alignment and magnitude measurements are necessary.

4. Impact on Spacecraft

An astronaut will be required to prepare the gas-droplet mixtures of large droplets in the orbital environment. Progress of the experiment must be monitored by taking measurements, on the basis of which control or decision are exercised. This includes the visual judgment of liquid film motion and aerosol size distribution. About 200 w of power will be necessary. Each experiment run sequence, including setup and monitoring, will require approximately 30 minutes. The necessary crew skills are reasonably minimal, requiring knowledge of photography and acquaintance with the test procedures of this research cluster. To ensure success in reaching the cluster's objective, it is necessary for the crew to communicate experimental results to the ground-based scientists and to observe anomalies that may influence the course of the experimental runs.

5. Required Supporting Technology Development

The necessary supporting research and technology are similar to the requirements for several other research clusters in the Physics and Chemistry Laboratory. The experimental facility requires assembly and testing in a 1-g environment to establish 1-g data for comparison with zero-g test data and to train the astronauts in the experiment procedures. An accurate low-g accelerometer capable of operating in the 10^{-6} range must be developed for the successful deployment and utilization of the Earth orbital facility. With the development of the facilities described above for determining zero-g effects on liquid releases and liquid drop size distribution, the necessary data concerning these transport processes can be generated to support future fluid system design and development.

6. References

1. H. N. Abramson. The Dynamic Behavior of Liquids in Moving Containers. NASA SP-106, 1966.

2. R. S. Brodkey. The Phenomena of Fluid Motions. Addison-Wesley, Reading, Massachusetts, 1967.

3. J. O. Fredrickson and J. D. Schweikle. Thermo and Hydrodynamic Experiment Research Module, Project Thermo Final Report, DAC-60594, March 1967.

4. C. C. Lautenbacher. The Collision of Fluid Droplets, Technical Report No. 2, Division of Engineering and Applied Physics, Harvard University, May 1966.

Critical Issues Addressed by Research Cluster

4-P/C-9

EFFECTS OF ZERO-G ON LIQUID RELEASES, SIZE DISTRIBUTION OF LIQUID DROPS

4.1.4.2.3.6.1
What are the effects of zero-G on liquid releases and the size distribution of liquid globules?

RESEARCH CLUSTER
NO. 4-P/C-9

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
4-P/C-9												
-1	Set-up Test Apparatus	Chamber	3	None		19-B	*	60	1			
-2	Checkout Instrumentation		4	"		19-B		60	1			
-3	Initiate Data Recording (Flow rate, temp, humidity, aerosol size distribution)	Visual and Sensor Recording	8	"		19-B		60	1			
-4	Initiate Experiment (Gas Flow)	Controls	5	"	X	7-B		60	1			
-5	Observe Droplet Shapes & Distribution		5	"	X	7-B		60	1			
-6	Terminate Test		5	"	X	7-B		60	1			
-7	Clean-up		4	"		22-C		60	1			

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.
*Estimate: 4 liquids, 4 thicknesses, 4 speeds ≈ frequency 64.

LEGEND OF CODES USED IN CREW ACTIVITY MATRIX

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS--SPACE PHYSICS

4-P/C-10

Capillary Flow in Zero-G

1. Research Objectives

The overall objective of this research cluster is to obtain information basic to the understanding of capillary flow in zero-g, such as that occurring in wicks, packed beds, and straight and converging channels. This information is required for the design of zero-g processing equipment, as well as for the evaluation and possible modification of present theories dealing with wicking velocities and flow through porous media (due to an imposed overall pressure difference), which have been compared with 1-g experiments only. Wicking and its contribution to flow through porous media are of primary interest in low gravity since the high wicking rates are difficult to simulate under normal gravity conditions.

2. Background and Current Status

The capillary flow of liquids in screen wicks, packed beds, and various capillary channels in low-g are of interest since the velocities caused by interaction of the liquid-vapor surface energies (surface tension) with the various solid specimens are difficult to simulate under normal gravity conditions. Knowledge of the mechanics of this interaction will contribute not only to the basic scientific knowledge of capillary flow but also to the design confidence required for future-generation space process equipment that makes use of this phenomenon. In the generalized capillary flow equations, the terms for momentum change and end drag can be neglected for low wicking velocities. At the anticipated high wicking velocities in low gravity, the above terms are significant, necessitating numerical solution of the complex equations. Low-gravity data are thus required to assess the magnitude of these terms.

3. Description of Research

The overall methodology consists of the experimental observation of the flow of various liquids in wicks, packed beds, and straight and converging capillary channels in suitable test enclosures. Wicking rates as well as flow under imposed overall pressure differences will be studied. The hysteresis effect of contact angle will be considered by flowing the various fluids through dry and wetted porous materials and channels. Primary data will be controlled by noting the volume change of bladdered liquid samples

at one end of a test specimen, visual observation of motion of the liquid-vapor interface, and the change in temperature at a particular location of a heated test element as the liquid-vapor interface arrives at the location. The facility will be such that a wide variety of liquids and test articles can be studied.

Bladdered fluid reservoirs will provide a positive supply of each of three test liquids to a test section that may contain either a screen wick, a dry or wetted packed bed, or straight or convergent capillary channels. Parameters to be measured are heater power, height of wick, time, temperature, pressure, pressure drop, and flow rate. A TV camera shall be positioned so that it will record the liquid behavior in the test article and gauge readings of the heater power, time, temperature, test chamber pressure and pressure drop, and flow rate (when an overall pressure gradient is imposed).

4. Impact on Spacecraft

An astronaut will be required to set up the test by inserting the appropriate test specimen and to initiate the test by opening the desired liquid-supply valve. He must activate the camera, monitor the tests, and upon observation of predetermined phenomena (e.g., decrease in wick temperature or visual appearance of liquid at the end of the test specimen) terminate the test. An average power of 250 w is required for the test, and each test run should require about 15 minutes to complete. Only one astronaut will be required for all tasks, with normal physical dexterity being the only skill requirement.

5. Required Supporting Technology Development

As with many of the other research clusters in the Physics and Chemistry Laboratory, a low-g accelerometer that measures accelerations as small as 10^{-6} g must be developed. Ground experiments using the zero-g facility, hot fluids, and materials must be performed before the flight to train the astronauts and establish 1-g test results that can be compared with subsequent low-g orbital tests. Comparison of time required by the astronaut for a given task in orbit with that required during Earth-based checkout tests will provide information concerning the astronauts dexterity in low-g. The Earth orbital experimental facility for studying capillary flow will be constructed in such a manner that a variety of fluids and capillary test specimens can be studied without major modifications. The basic data generated by this facility will provide a better understanding of capillary flow and be useful for the design of low-g processing equipment that is based on capillary phonomena.

6. References

1. H. N. Abramson. The Dynamic Behavior of Liquids in Moving Containers, NASA SP-106, 1966.

2. R. S. Brodkey. The Phenomena of Fluid Motions. Addison-Wesley, Reading, Massachusetts, 1967.

3. S. Chandrasekhar. Hydrodynamic and Hydromagnetic Stability, Oxford, London, 1961.

4. J. O. Fredrickson and J. D. Schweikle. Thermo and Hydrodynamic Experiment Research Module in Orbit Project Thermo Final Report, DAC-60594, March 1967.

Critical Issues Addressed by Research Cluster

4-P/C-10

CAPILLARY FLOW IN ZERO-G

4.1.4.2.3.1.1
How does the capillary flow in zero-G depend on the properties of liquids and surfaces?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO. 4-P/C-10

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
4-P/C-10												
-1	Set-up Test	Transparent Chamber	3	None		19-B	144	10	1			
-2	Checkout Instrumentation		4	"		19-B	144	10	1			
-3	Initiate Data Recording (Heater power, pressure, time, temp)	Video Recording	8	"		19-B	144	10	1			
-4	Initiate Experiment	Pressure Regulator	5	"		7-B	144	10	1			
-5	Observe Vapor Formation, Record Temperature		5	"	X	7-B	144	10	1			
-6	Terminate Test		5	"		7-B	144	10	1			

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

LEGEND OF CODES USED IN CREW ACTIVITY MATRIX

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS--SPACE PHYSICS

4-P/C-11

Behavior of Superfluids in the Weightless State

1. Research Objectives

The objective of this research cluster is to gather low-g experimental data about the behavior of superfluids in space. In particular, the influence of the gravity level on the fountain and creeping-film effects will be investigated. This information will be of use in the basic understanding of the hydrodynamic behavior of superfluids and in the design of support equipment needed for the future use of space, such as cooling superconducting magnets and infrared sensors.

2. Background and Current Status

Excellent agreement between existing theories and 1-g experimental results using liquid helium has been obtained for the fountain effect, whereby the level of liquid in a vessel communicating through a narrow capillary to a surrounding bath of liquid rises above that of the surrounding bath when heat is supplied electrically to the liquid in the vessel. There is no central comprehensive theory that adequately predicts the 1-g experimental results of tests involving the creeping-film effect, whereby the levels of liquid in two concentric vessels placed one within the other soon become equalized without the presence of an opening or communicating tube between the two vessels. No data are available concerning these effects in reduced-gravity environments.

3. Description of Research

The experimental approach to the study of these effects in low-g environments is to use a low-temperature dewar constructed with one or more viewing ports and to visually observe the behavior of liquid helium inside. A concentric capillary tube with a wider section below it will be used to observe the fountain effect. The lower tube, whose bottom is open to the dewar and which contains an electrical heating wire, is filled with grains of finely ground emery. The use of a fountain of liquid helium from the capillary tube upon the heating of the wire will be measured visually. To observe the creeping-film effect, the liquid transfer rate of helium to or from the inside of an open-ended cup partially submerged in a bath of liquid helium will be determined visually or by weighing through the use of an external load cell mechanically connected to the test cup.

The astronaut will take an active part in conducting the tests. He must initiate the test by remotely lowering the test article into the liquid helium bath, then activate appropriate visual-recording equipment and monitor the test. The astronaut will also be required to use his judgment in terminating the test and setting up another.

4. Impact on Spacecraft
An astronaut will be required to fill the dewar with helium II, record the appropriate measurements, and monitor the tests. The power requirements are those associated with the storage of liquid helium and should be no more than 300 w. Thirty minutes will be required to set up and conduct each test. Although specific required crew skills are not great, the liquid helium must be handled very carefully. The exact impact that storing liquid helium and converting it to helium II has on the orbiting vehicle cannot be assessed, because this facility is yet to be designed. Some interfacing with other experiments to make mutual use of cryogenic fluids may be possible and should be considered.

5. Required Supporting Technology Development
The experimental facility requires assembly and testing in a 1-g environment to establish baseline data and to train the astronauts in the experimental procedure. As with the other research clusters in the Physics and Chemistry Laboratory, an accurate low-g accelerometer capable of operating in the 10^{-6} g range must be developed. The facility for storing liquid helium and converting it to helium II in a space environment (if it cannot be stored completely in the helium state) must also be designed. With the development of these facilities the detailed study of the fountain and creeping-film effects of a superfluid at low-g will provide valuable information for understanding the behavior of superfluids.

6. References

1. F. E. Hoare, L. C. Jackson, and N. Kurti. Experimental Cryophysics. Butterworth Scientific Publications, London, 1961.

2. C. T. Lane. Superfluid Physics, McGraw-Hill Book Company, New York, 1962.

3. M. W. Zemansky. Heat and Thermodynamics, Fifth Edition, McGraw-Hill Book Company, New York, 1968.

RESEARCH CLUSTER
NO. 4-P/C-11

Critical Issues Addressed by Research Cluster

4-P/C-11

BEHAVIOR OF SUPERFLUIDS IN THE WEIGHTLESS STATE

4.1.3.1.3.4.1
How do superfluids behave in the weightless state?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO. 4-P/C-11

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
4-P/C-11												
-1	Prepare Chamber	Dewar Container	3	None		7-B	60	↑	1			DUPLICATE EXPERIMENT IN ONE-G
-2	Initiate Video Recording	TV Recording	8	"		19-B	60		1			
-3	Initiate Test - Introduce Test Object	Cylinder	5	"	X	7-B	60		1			
-4	Observe Superfluidity Effects		5	"	X	7-B	60	60	1			
-5	Record Temperatures and Spatial Measurements		5	"	X	7-B	60		1			
-6	Terminate Test		5	"	X	7-B	60		1			
-7	Remove Test Object		4	"		7-B	60		1			
-8	Remove Helium from bath		4	"		7-B	60	↓	1			

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

LEGEND OF CODES USED IN CREW ACTIVITY MATRIX

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS--SPACE PHYSICS

4-PP-1 Spacecraft Environment Interaction

1. Research Objectives

The prime objectives of this research cluster will be to determine the properties and spatial extent of the disturbed plasma volume generated by the passage of a large body through the ambient neutral particle and plasma environment. Such a detailed set of measurements in the region surrounding the station and other large bodies of different shape will provide needed experimental results for comparison with theoretical predictions. Furthermore, measurements in the environment surrounding the space station will define where, in relationship to the station, it will be possible to carry out the desired unambiguous local environmental measurements (identified in the list of critical issues) and low-energy plasma physics experiments. Lastly, the wake itself may serve as a useful tool for achieving desired environmental perturbation.

2. Background and Current Status

Wake physics has been the subject of extensive theoretical study[1, 2]. The main predictions have been limited to the altitude range between 150 and 1,000 km, where the absence of particle collisions permits the decoupling of the perturbations generated in the charged and neutral ambient constituents, and the spacecraft velocity is greater than the thermal velocity of the ambient ions. In general, these theoretical predictions are based upon single-particle models and neglect the collective effects and possible plasma instabilities[12] that may be produced. Furthermore, the spacecraft is assumed to be an entirely passive body, and no consideration is given to possible modifications that can arise because of electric fields, magnetic fields, gaseous effluents, etc., which may be associated with the spacecraft itself.

Only a very limited number of in situ wake measurements have been performed to date[6, 7, 10, 11]. These were limited to relatively small-sized vehicles (Explorer VIII and XXXI, Ariel 1, and Gemini-Agena during the docking procedure). Although all these measurements were limited to only one diagnostic (Langmuir probe) and extended over a very limited spatial extent, the expected large decrease in electron density in the wake and its dependence on the dominant ion mass were observed, together with turbulence, in the wake. It is extremely difficult, if not impossible, to simulate the wake interaction in a laboratory configuration. The wake is in some respects a rather dynamic phenomenon. It depends upon the shape and dimensions of the body and upon the orientation of the body's velocity vector with respect to the geomagnetic field. It is also directly related to the ambient plasma characteristics of (1) electron thermal

velocity, (2) electron density, (3) ion thermal velocity, (4) ion composition and density, (5) neutral gas composition, (6) vehicle potential, (7) magnetic field magnitude and direction, (8) ac and dc electric fields, (9) solar ultraviolet flux, and (10) possibly the incident energetic particle flux.

3. Description of Research

The spatial extent of the disturbed region produced by a passive vehicle has been theoretically estimated[1] to extend to about five space vehicle radii in the forward and lateral directions and up to fifty radii in the backward direction. The wake volume can be separated into essentially three regions: the Debye sheath, the near wake out to about five space vehicle radii, and the remaining far-wake region. The first two regions can probably be examined from the space vehicle itself by using surface and boom-mounted probes that can effectively sweep the near wake. The far wake will require either tethered diagnostics or (more preferable) several small, maneuverable satellites.

The most convenient instruments for these measurements will be extensions of the Langmuir probe technique using retarding potential analysis for density and temperature measurements, a mass spectrometer for ion analysis and neutral gas composition, a fluxgate magnetometer for magnitude and direction of the local magnetic field, a search coil for fast magnetic field changes, and electrostatic probes for fluctuating electric field measurement. These measurements need to be made for as wide a variation in vehicle orbit as possible. Since night/day and other variations will occur, repeated measurements will be necessary to confirm the nature of these changes. The variety of vehicle shapes and dimensions that are required for a complete experimental test of the theoretical predictions can be supplied by inflatable balloons. These could be similar in construction to those developed for the ECHO program and could have outer skins made of conducting and insulating materials. They would measure the effect of the $\overline{V} \times \overline{B}$ electric field produced and would form the basis for wake-wake interaction studies. An important consideration would also be to obtain measurements of the undisturbed region at the same time, together with extensive measurements of the solar flux variations.

4. Impact on Spacecraft

The large amount of instrumentation necessary to conduct the experiments has a major impact on the spacecraft in terms of data requirements, maintenance of subsatellites, and boom requirements. Other requirements such as power, weight, and volume, although quite large due to the number and length of operating time of the experiments, should not be excessive.

The data load can be eased by recording on magnetic tape and by onboard monitoring of the data for scientific value. The resulting data transfer operation can be accomplished by fast dumping of

the recorded data and transfer of the bulk tape during the visit of crew changes or maintenance vehicles. Maintenance of the apparatus on the spacecraft surface and of booms and satellites should be kept to a minimum by replacement of complete modules where possible but will be limited by service vehicle visits and carrying capacity. The satellites will require docking, fuel, and control facilities and probably will transmit data to the main space vehicle for analysis and transmission to the ground. If the space station has no axis of rotation, the examination of the near wake will require movable booms, i.e., provisions must be included for variation of boom length and angle to be made from inside of the space vehicle.

The manned participation in this operation will most probably be in terms of control of the satellites and booms, data monitoring for scientific value, and maintenance. A physicist will therefore be required to conduct the experiment and, in conjunction with the ground specialist, will decide on experimental planning and the monitoring of the data for scientific content. Maintenance of the equipment, and satellite and boom control will be performed by an electromechanical technician. The presence of these men would ideally be preferred throughout the experimental period but if necessary automated control with several visits during the experimental period may be adequate.

Power (watts)	Weight (lb)	Volume (cu ft)	Crew Time	Crew Skill
200	1,100	10	~1 week per month	Physicist, Electromechanical Technician

This is an estimate of equipment requirements only; no estimate is included for data storage or satellite size, fuel, control or docking requirements.

5. Required Supporting Technology Development

The present instrument capability is nearly adequate for the proposed experimental program in its initial stage. The exception here is the development of a small-dimension, high-sensitivity dc field diagnostic. The main areas requiring development are in onboard data compression and processing and in the design of maneuverable booms and satellites. Another important item is the outer skin of the space vehicle; this ideally would be a uniformly conducting surface. This may not be possible in practice but nonconducting surfaces should be kept to a minimum.

6. References

1. Ya. L. Alpert, A. V. Gurevich and L. P. Pitaevski, Space Physics with Artificial Satellites Consultants Bureau, New York (1965).

2. V. C. Liu, Space Science Reviews, 9, 423 (1969).

3. J. J. Shea, Missile-Plasma Interaction Phenomena Final Report, Contract AF-19(628)-1964, Cosmic, Inc., 3206 Grace St., N. W., Washington D. C. 20007 (1964).

4. D. F. Hall, R. F. Kemp and J. M. Sellen, Jr., AIAA Journal 2, 1032 (1964).

5. C. L. Henderson, and U. Samir, Planet Space Sci., 15, 1499 (1967)

6. U. Samir, and A. F. Willmore, Planet Space Sci., 13, 285 (1965).

7. U. Samir, J. Geophys. Res., 75, 855 (1970).

8. J. M. Sellen, Jr., paper presented at the AIAA Joint Electric Propulsion and Plasmadynamics Conference, Colorado Springs, Colorado, Sept. 1967.

9. J. J. Shea, Radar Scattering from Satellite Wakes Final Report Contract AF-30(602)-3678, Cosmic, Inc., 3206 Grace St., N. W., Washington D. C. 20007 (1964).

10. P. J. Bowen, R. F. Boyd, W. J. Raitt and A. P. Wallmore, Proc. Ray Soc., 281, 504 (1964).

11. R. E. Bourdeau, and J. L. Donley, Proc. Ray Soc., 281, 487 (1964).

12. E. C. Whipple, Round table discussion, Annual Meeting, Am. Gephys. Union, Washington, D. C., April 1970.

13. H. A. Taylor, H. C. Brinton and C. R. Smith, J. Geophys. Res. 70, 5769 (1965).

14. R. S. Narcisi, and A. D. Bailey, J. Geophys. Res. 70, 3687 (1965).

15. A. O. Neir, J. H. Hoffman, C. Y. Johnson and J. C. Holmes, J. Geophys. Res. 69, 979 (1964).

16. P. J. Bowen, R. L. F. Boyd, C. L. Henderson and A. P. Willmore, Proc. Ray Soc., 281, 514 (1964).

17. C. G. Crook, F. L. Scarf, R. W. Fredricks, I. M. Green and P. Lukas, IEEE Trans. Geoscience Elec. GE-7, 2, 120 (1969).

18. S. D. Shawhan, and D. A. Gurnett, J. Geophys. Res. 17, 5649 (1968).

19. W. Bernstein, G. T. Inouye, N. L. Sanders and R. L. Wax, paper presented at Conference on Electric Fields in the Magnetosphere at Rice University, Houston, Texas, March 1969.

20. W. Bernstein, G. T. Inouye, N. L. Sanders and R. L. Wax, Final Report Contract NASW 1474, TRW Systems Report 06484-6007-RO-OO, Redondo Beach, California 90278 (1968).

21. S. D. Drell, H. M. Foley, and M. A. Ruderman, Phys. Rev. Lett. 14, 171 (1965).

22. W. Parker, and B. L. Murphy, J. Geophys Res. 72, 1631 (1967).

23. L. M. Linson, J. Geophys. Res, 74, 2368 (1969).

24. C. D. Florida, Proc. IEEE, 57, 867 (1969).

25. R. K. Cole, and J. M. Sellen, Jr., J. Spacecraft and Rockets, 4, 674 (1967).

Critical Issues Addressed by Research Cluster 4-PP-1

SPACECRAFT ENVIRONMENT INTERACTION

4.1.6.4.3.2.2
: 1 Can Alfvén waves be propagated in the magnetosphere or ionsphere?

4.3.1.1.3
: 2 What effect does the spacecraft potential distribution have on the wake?

4.3.1.2.1
: 1 How does leaking and outgassing affect the properties of the space environment?

4.3.1.2.2
: 2 How are particle measurements influenced by the satellite environment?

4.3.1.2.3
: 2 What is the chemical composition of the contaminating gases surrounding the spacecraft at various distances and angles from the spacecraft?

4.3.1.2.4
: 0 How do plasma and ion propulsion devices interact with the environment?

4.3.1.2.5
: 1 What factors affect vehicle drag characteristics?

4.3.2.1.1
: 1 What is the lowest achievable vacuum near the spacecraft?

4.3.2.1.2
: 2 How does the spacecraft wake affect environmental measurements?

---

[0] Related to research area but implementation would require expansion of the experimental techniques described herein.

[1] Related to research area but only partially answered by the experimental techniques described herein.

[2] Fully answered by the experiment techniques described herein.

4. 3. 2. 1. 3
2 What effect does vehicle shape and size have upon the spacecraft wake?

4. 3. 2. 1. 4
1 What effect do high power antennas have on the vehicle wake?

4. 3. 2. 1. 5
1 Are waves produced in the wake region?

4. 3. 2. 1. 6
2 How can subsatellites be used to measure the wake?

4. 3. 2. 1. 7
2 What is the electric field distribution in the near-wake region of the spacecraft?

4. 3. 2. 1. 8
2 How does the magnetic field orientation affect the wake characteristics?

4. 3. 2. 1. 9
2 How will using long VLF antennas affect the spacecraft potential and wake geometry?

4. 3. 2. 2. 1
1 What are the temperature conditions near the spacecraft?

4. 3. 2. 2. 4
How does solar ultraviolet irradiation affect the spacecraft potential?

---

[1] Related to research area but only partially answered by the experimental techniques described herein.

[2] Fully answered by the experiment techniques described herein.

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
4-PP-1 -1	Prepare mapping vehicles for release		3	None		21 B		1	*	1		
-2	Release and position mapping vehicles for wake observations		5	None	X	21 B	1		1			
-3	Stabilize and orient mapping vehicles for sensor coverage		5	None	X	7A	1		1			
-4	Initiate sensors and monitoring equipment	TBD	5	None		7A	1		1			
-5	Monitor sensor operation, data collection and display equipment	TBD	8	None		7A	Periodi-cally		1			
*	Individual tests may take 1 to 2 hours											

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

LEGEND OF CODES USED IN CREW ACTIVITY MATRIX

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS--SPACE PHYSICS
4-PP-2
Energetic Particle Dynamics in the Magnetosphere

1. Research Objectives

The fundamental objectives of this research cluster are to identify the origin of the trapped energetic particles and to understand the dynamic processes that result in their energization, trapping, and loss. Because of the multiplicity of simultaneously occurring processes, this cluster has been restricted to selected experiments which, it is believed, will clarify the role of specific physical processes that have been theoretically proposed. In addition, experiments are described that will provide measurements of the electric and magnetic field topology to a greater accuracy than is possible at present. These latter measurements not only will furnish a framework for interpretation of magnetospheric physics but also will play an important role in the interpretation of the experiment described in the auroral cluster.

The specific issues covered by this program are indicated on the included list and are linked to the NASA objective to obtain a detailed understanding of the physical interaction processes that control the Earth's space environment.

2. Background and Current Status

The main energetic particle constituents in the magnetosphere are electrons and protons. Alpha particles have been detected, but observations of variations in their abundance and spatial distribution are limited. The energy ranges from hundreds of ev to several Mev for electrons, whereas proton energies range up to several hundred Mev. The lower-energy particles extend throughout the magnetosphere, although certain natural boundaries can be defined for various classes of particles. The most energetic electrons exist at about $L = 3, 4$ whereas the protons peak at $\sim L \doteq 1.5$. An artificial belt of high-energy electrons (>1 Mev) from the Starfish nuclear test program still dominates the low L-shells but is slowly decaying. The source of the very-high-energy protons is assigned to the decay of cosmic ray albedo neutrons.

The specific problems selected for study include:

A. Collective Loss Processes That Limit Trapped-Particle Populations--Processes by which the belt populations are controlled have been suggested by various authors[1, 2, 3]. In one such process, once the energetic particle density exceeds a critical value, the particles stimulate their own VLF emissions on field lines close to the equatorial region. Wave-particle interactions then occur that produce radial particle acceleration, wavegrowth, and finally particle

precipitation. The process proposed is self-governing, and estimates seem to be in good agreement for L > 4. For lower L-shells, the measured energetic-particle density appears well below that required for this instability and this mode of precipitation does not appear. Injection of energetic particles from the space laboratory into an L-shell where the energetic-particle density is near to the calculated critical flux could trigger the process and produce measurable stimulation of VLF and particle precipitation into the atmosphere.

B. Transport of Protons From the Magnetospheric Boundary to Low Shells -- Early in the space program, Davis and Williamson[16] mapped the proton flux and energy distribution in the magnetosphere. They found a steadily increasing proton energy with decreasing L-value. The observed fluxes were stable and showed little temporal variation. Nakada and Mead[17] were able to derive this observed energy spectrum analytically on the assumption that a minor fraction of the proton flux in the transition region penetrated the magnetosphere and was transported across L-shells by a stepwise process based upon violation of only the third adiabatic invariant. Because the first two invariants are conserved, this mode of particle transport is also accompanied by the stepwise energization of the particles. In this calculation, the only loss processes were assumed to be charge exchange and collisional scattering, and the stepwise inward motion was taken as being caused by the magnetic field modification associated with geomagnetic storms. On the other hand, faster diffusion processes caused by wave-particle interactions (and usually identified as Bohm diffusion) may also play an important role in magnetospheric processes. Because the particles are effectively decoupled from the magnetic field by these collisions, energization is not a fault. Frank has suggested that a transport mechanism of this type may be associated with the nearly simultaneous observation of fluxes of 5- to 50-kev protons in the solar wind and at L = 3 to 4 during geomagnetic storms. Experiments that can differentiate between these modes of transport are important in understanding magnetospheric phenomena.

C. Magnetospheric Structure -- The magnetic field tracer experiment has already reached the initial experimental phase. An experiment carried out from an Aerobee rocket[11] injected a 5-kw electron beam down a field line into the atmosphere. The resulting artificial aurora was photographed by an image orothicon system[12] for electron pulses of 1-sec duration. Another group[13] has successfully fired a 40-kev electron beam with a large

pitch angle up a field line from a rocket. The same rocket was then used to detect the beam reflected from the opposite hemisphere. This general technique therefore appears quite attractive, especially since little in the way of beam instabilities has been observed. However, since future experiments will require higher beam powers, beam instabilities may still occur.

3. Description of Research

A. Collective Loss Processes -- A practical investigation into the theoretical estimates of the critical densities for the belt populations can be performed in several ways. One of these is to inject a large flux of 40-kev electrons at about L = 4 when the shell is near its theoretical 40-kev critical population level. This may initiate the self governing processes; however this may be inconclusive, as natural processes could still have been involved. It has also been suggested[14] that large fluxes of 300-kev electrons should be used due to their long lifetime. Also, the VLF produced is then characteristic of this particular energy and therefore easily identifiable. The power levels that were estimated are of the order of a kilowatt of power for about a week. Electron injection is required since the critical mechanism, for the self-limiting processes, is limited with respect to flux, not density.

B. Transport of Protons from the Magnetospheric Boundary to Low Shells -- The investigation into particle L-shell diffusion processes requires the injection of a tracer particle that can easily be identified throughout the various L shells. It would appear that the best technique would be to inject a low-energy (~ solar wind velocity 1kev) lithium or barium ion flux at high L-shell values. This flux would ideally be traced with satellites equipped with a mass spectrometer and energy analyzers to determine the inward diffusion rate and any energy changes. This experiment is obviously extremely difficult to conduct and its interpretation appears rather difficult even if successfully accomplished, but does merit possible study.

C. Magnetospheric Structure -- The use of energetic particle beams as a tracer to determine magnetic field configuration does however represent a quite feasible experiment.

A low-energy (9 kev) electron beam suitable for aspects of this program has already produced a photographable artificial aurora. Also a flux of 40 kev electrons has been successfully propagated from one hemisphere to the other and back. These demonstrations indicate a possible method of making the required measurements. The electron beam, with an energy of 10 kev and a current of about one amp, would be injected from the space vehicle in pulses of one second duration. Artificial aurora would then be produced by the beam in the far hemisphere and by the reflected beam below the space vehicle. These could be detected by sensitive TV systems from ground stations and from the space laboratory. In this general manner, field line length conjugate point determination and open and closed field lines could be investigated. There is also the possibility of using ions; this appears especially attractive in the case of barium. If large fluxes of a few kev barium ions could be injected in a manner similar to what has already been described, induced emissions from solar UV excited barium ions may possibly allow observation of the complete path of these ions along the field lines. An estimate[14] of the necessary source requirements is for a~6 kev, 12 kw/sec burst using a converted Kaufmann thruster[15].

4. Impact on Spacecraft

The scope of this research cluster depends heavily on the resources of the spacecraft. Power requirements appear to be of the general order of tens of kilowatts per second for particle injection and therefore spacecraft power capability will determine the number of such pulses possible. This also directly relates to weight and volume limitations as large numbers of batteries will be required unless some form of generator is available. The data rates will be extremely high for good TV coverage but, as pulse rates will be low due to the power requirements, storage on video tape for transfer during low data rate periods will be possible.

In terms of integrating the experiment on the spacecraft, a major problem could be the increase in spacecraft potential during beam propagation. This will be especially severe for high altitude stations due to the lack of a local source of neutralizing current, and therefore simultaneous injection of ion fluxes will be necessary. For low altitude positions an artificial

increase in spacecraft surface area may be adequate. The high voltage systems will ideally be located outside the space laboratory as a safety precaution and to reduce the probability of corona discharges. The latter, however, may still be present if local high-pressure gas pockets are caused by spacecraft systems. Also a provision for moving the accelerator back into the space laboratory, through an airlock, for regular maintenance will be necessary.

The accelerator maintenance will be a major requirement on crew participation. Specifically, the ion sources of accelerators are very prone to electrical discharges and filament destruction. The system will be as nearly automated as possible with the requirement of a physicist to plan experimental procedures and monitor data. An electromechanical technician for maintenance and repair will be necessary to work in conjunction with the physicist, especially in the early setting up phases.

5. Required Supporting Technology Development

The major supporting research and technology necessary to implement this cluster is in the development of high-intensity energetic particle sources suitable for spacecraft operation. The necessary technology for building the systems has already been developed for laboratory applications. Almost as important for this research cluster and many others is the need for large continuous sources of power. It would appear that a program to provide a generator of small size, low noise and effluent output and producing a minimum of vibration would be a tremendous asset.

6. References

1. R. A. Helliwell. Journal of Geophysical Research, Vol. 72, 1967, Page 4773.

2. C. F. Kennel and H. E. Petschek. Journal of Geophysical Research, Vol. 71, 1966, Page 1.

3. J. M. Cornwall. Journal of Geophysical Research Vol. 71, 1966, Page 1285.

4. J. W. Dungey. Space Science Review, Vol. 4, 1965, Page 199.

5. C. G. Falthämmer, Journal of Geophysical Research, Vol. 71, 1966, Page 1487.

6. M. P. Nakada, J. W. Dungey, and W. N. Hess. Journal of Geophysical Research, Vol. 10, 1965, Page 10.

7. J. W. Cornwall, Journal of Geophysical Research 71, 1966, Page 2185.

8. K. A. Anderson, Proceedings of Symposium on Particles and Fields in the Magnetosphere, Ed. by B. M. McCormac and held at the University of California at Santa Barbara, 1969.

9. W. N. Hess, Report of Ad Hoc Committee on Environment Modification Experiments in Space, University of Maryland, 1968.

10. W.I. Axford, Journal of Geophysical Research, Vol. 1968, Page 6855.

11. W.N. Hess, Science, 164, 1519, 1969.

12. T. N. Davis, et al., Grand Observation of an Artificial Aurora Generated by a Rocket Borne Accelerator, presented at 50th Annual AGU Meeting, 1969.

13. J.R. Winkler, University of Minnesota Electron Beam Experiment 1970, to be published.

14. C. F. Kennel, Report of Ad Hoc Committee on Environment Modification Experiments in Space, University of Maryland, 1968.

15. H.E. Petschek, Report of Ad Hoc Committee on Environment Modification Experiments in Space, University of Maryland, 1968.,

16. L.R. Davis and J.M. Williamson, Space Res., 3, 365, 1963.

17. M.P. Nakada and G.D. Mead, "Radiation Trapped in the Earth's Magnetic Field, "Proceedings of Advanced Research Institute, Aug 1965.

Critical Issues Addressed by Research Cluster

4-PP-2

ENERGETIC PARTICLE DYNAMICS
IN THE MAGNETOSPHERE

4.1.5.2.5.3.1
 1 How can electron-beam accelerators be used in orbit to simulate certain geophysical phenomena?**

4.1.6.3.1.1.1
 1 How do magnetospheric observations correlate with laboratory mirror experiments?**

4.1.6.3.1.1.3
 1 Are the superthermal particles observed in space produced by processes similar to those that occur in high-energy laboratory plasma-physics experiments?**

4. 2.1.2.1.3.4.1.1
 1 What is the vector magnetic field present at each point in the ionosphere?††

4.2.1.2.1.3.4.1.1.1
 1 Are field lines in the polar regions open or closed?††

4.2.1.2.1.3.4.1.1.2
 1 Can conjugate point locations be determined to 1 km or better?

4.2.1.2.1.3.4.1.1.3
 2 Are there diurnal or seasonal variations in conjugate point locations?††

4.2.1.2.1.3.4.2
 2 What is the luminous efficiency of ion beams interacting with the upper atmosphere?††

4.2.1.2.1.3.5.1
 1 Are the energetic particles in the Earth's magnetosphere solar or terrestrial in origin?xx

4.2.1.2.1.3.5.1.1
 0 Does magnetic field annihilation occur in the magnetospheric tail to give energetic particles?

**Refers to Research Objective A
xxRefers to Research Objective B
††Refers to Research Objective C

4.2.1.2.1.3.5.1.2
1 Where does the solar-wind plasma enter the magnetosphere, and how does it flow toward the Earth? xx

4.2.1.2.1.3.5.1.2.1
0 What are the plasma-flow characteristics in specific regions of magnetosphere, such as the magnetosheath? xx

4.2.1.2.1.3.5.1.3
0 Does natural injection occur from the interplanetary medium into the magnetosphere?

4.2.1.2.1.3.5.1.4
1 Can tracer elements be injected to permit unambiguous separation of particle gain and loss processes? xx

4.2.1.2.1.3.5.2.2
2 What conditions does the environment impose on a particle beam injected as a diagnostic tool into the magnetosphere? ††

4.2.1.2.1.3.5.3
1 What information about the environment can be derived from high-altitude detonations? What type of detonations would be useful for these investigations? xx

4.2.1.2.1.3.5.3.1
0 Can barium be released in the magnetospheric tail to determine the structure of magnetic field lines? ††

4.2.1.2.1.3.5.3.1.1
1 What is the geometry of magnetic field lines at specific locations of the space environment? ††

4.2.1.2.1.3.5.3.1.2
1 How can it be measured? ††

4.2.1.2.1.3.5.3.1.3
1 What is the geometry of electric field lines at the same locations? ††

4.2.1.2.1.3.5.3.1.4
1 How can it be measured? ††

4.2.1.2.1.3.5.4
1 How stable is the magnetosphere, i.e., what is the lifetime of an ion in the magnetosphere? **xx

---

**Refers to Research Objective A
xxRefers to Research Objective B
††Refers to Research Objective C

4.2.1.2.1.3.5.4.1
0 Is the tearing mode instability active in the magnetospheric tail? If not, what determines the rate of merging?**

4.2.1.2.1.3.5.4.2
0 Are flute loss cone, or ion cyclotron instabilities active in the magnetosphere?**

4.2.1.2.1.3.5.4.4
0 Is the nondipole nature of the Earth's field sufficient to insure particle instability?**

4.2.1.2.1.3.5.5.2
1 Can trapped energetic particles be accelerated by electromagnetic irradiations?**

4.2.1.2.1.3.5.5.2.1
1 What radiation power is required to reduce significantly the level of dangerous radiation reaching astronauts?**

**Refers to Research Objective A

NO CREW ACTIVITY MATRIX DERIVED

FROM THIS CLUSTER (4-PP-2)

RESEARCH CLUSTER SYNOPSIS--SPACE PHYSICS
4-PP-3
Thermal Plasma in the Ionosphere and Magnetosphere

1. Research Objectives

The prime objectives of this research cluster are to understand the processes by which the ionospheric and magnetospheric thermal plasma is formed and the processes by which it is controlled and distributed through the magnetosphere. These objectives relate directly to the NASA objective to obtain a detailed understanding of the physical interactions and dynamic processes which control the earth's space environment.

2. Background and Current Status

The behavior of the plasma in the ionosphere is governed to a major degree by the geometry of the geomagnetic field. In the region out to the plasma pause boundary, the position of which varies but is located at about four earth radii, the field lines are closed. This plasma, the ionosphere, is therefore contained close to the earth and diffusive equilibrium between the different ion species is the generally observed condition. At higher latitudes the field lines lead into the magnetospheric tail, and the magnetospheric plasma is not contained in a closed geometry. Therefore it is much more able to assume a different density and velocity profile than the trapped ionospheric plasma. The plasma at high latitudes and at a height where the collision frequency is low is therefore depleted and this steady loss of plasma from the near earth environment is termed the polar wind[1]. Other factors influence this depletion such as gravity, which results in a preferential loss of low mass ions and electrons. The tail region is therefore though to be composed of plasma of terrestrial[1] and solar origin[2].

The processes that occur in the ionosphere are complex to understand but information on why the ionosphere has the characteristics it now possesses, can be obtained by slightly perturbing the local conditions and noticing the changes that occur. This can be done, for example, by radio frequency heating of the local plasma. The increase in plasma temperature changes the local chemistry; recombination of some ion species will occur while other gases will be ionized or dissociated, producing slightly different plasma characteristics.

As several of the ambient plasma natural oscillation frequencies occur in the radio frequency portion of the spectrum, the interaction of the radiated frequencies with the ambient plasma will stimulate plasma oscillations and, at higher radiated power, plasma heating will occur. The consequences of heating will most probably depend on the amount of power radiated and the direction of the wave.

This area of investigation is of special interest at present, due to the observation of 'ringing' phenomena observed on the ISIS[3] series of top side sounders and RF ionosphere heating experiments being carried out at Boulder[4]. Future satellites in the ISIS series will study harmonic resonance effects in greater detail but a space laboratory is an ideal environment from which to study this type of phenomena. The Boulder experiments are investigating ionospheric F region heating using a ground based two megawatt transmitter operating at about 7.7 MHz. Besides providing a greater understanding of plasma oscillations, sensitive techniques for examining ambient plasmas could result from these investigations.

Information on ionospheric processes can be obtained from the measurements of electric fields, especially in the equatorial and auroral regions. Measurements of this type have been made using barium cloud releases in the atmosphere[5]. A phenomenon common to most of these releases is the development of striations[6] or columns of enhanced ionization aligned with the magnetic field. Whether these observed striations are a function of the barium plasma or the local ambient plasma has not been determined. A study of the striations is also interesting in terms of what effect introducing very large amounts of ionized material into the aurora and ionosphere has upon local characteristics and in the understanding of high-altitude nuclear explosions.

3. Description of Research

A study of plasma resonances can be performed from the space station in a manner that is similar to that developed for the ISIS topside sounder program[8]. Radio frequency waves are propagated as fixed frequency short duration pulses from a dipole antenna. The frequency of each pulse is steadily varied until resonance with one of the natural plasma frequencies is achieved. The plasma response to the transmitted pulse is observed on a receiver that is also connected to the transmitting dipole, and therefore functions only during the nonpropagation periods between the pulses. The resonance is identified by a persistence of the radiated signal for long periods after the transmitted pulse ends. In order to check theoretical predictions of resonance structure, experiments need to be carried out on the effect of varying the orientation of the antenna with respect to the magnetic field and on the effect of variations in transmitted power. Also, the actual volume of space in which the resonance occurs needs to be identified together with many unexplained resonance phenomena[9].

Radio frequency irradiation of a plasma causes ionization of the neutral gas when the potential of the irradiating waves exceeds the breakdown voltage of the gas. However, the main heating process is caused by the energized electrons colliding with heavy local gas ions resulting in a loss of energy from the beam.

Furthermore if the frequency is close to one of the natural electron resonance frequencies, very strong absorption of the radio wave occurs. For cyclotron resonance heating in particular, the electron-ion collision frequency needs to be less than the electron's resonance frequency for the resonance energy transfer to be effective. This defines a low altitude limit to the process below which cyclotron heating will not occur. Above this low altitude limit, as the electrons become heated, only a small amount of this energy is lost in the electron-ion collisions and appreciable heating of the electrons is possible. The increase in particle pressure which occurs with the change in electron temperature results in the plasma expanding along the field lines, producing tubes of heated plasma confined by the magnetic field.

Large amounts of power (kilowatts) may need to be radiated from the space laboratory. The effects on the space plasma would be monitored by observations from the space vehicle. In this mode the density could be measured by ionosonde techniques and the electron temperature profile could be obtained from measurements of, for example, the 6300 A^{o} atomic oxygen lines. A more ideal technique would be for the measurements of local plasma parameters in the heated region to be carried out by a remote maneuverable satellite. Since the formation and use of alkali metal clouds is discussed in detail in another section[10], the similar techniques necessary for the formation of the striations will not be discussed here.

4. Impact on the Spacecraft

The major impact on the space station will be the power requirement necessary to attempt local plasma heating. The amount of power required has not been precisely determined but power levels up to tens of kilowatts for several seconds may be necessary. This will probably limit operation of the experiment to once or twice a day if batteries are the power source. The ideal requirement for diagnostic examination of the heated region involves the use of a remote maneuverable satellite, whose development is also necessary for the other experimental clusters.

In regard to the harmonic resonance experiment the major difficulty is likely to be caused by the noisy environment of the space station. This may seriously impair the capability of the receiver to distinguish the resonance condition from the noise. If this does occur, separate deployment of the antenna on a long boom or satellite may be required. The alkali metal cloud technique for examination of striations imposes the same restrictions on the space station as the similar case in 4-PP-4.

The required level of manned involvement in performing these experiments is mainly in the form of performing any necessary variation in experimental procedures and in the monitoring of the experiment and data for scientific value. The required level of skill here is that of an appropriate physicist and an electro-mechanical technician.

5. Required Supporting Technology Development
The degree of development necessary to conduct the alkali metal cloud is discussed in 4-PP-4 and mainly involves improvement in the ion yield from the chemical components. The other major item here is the development of rocket launching facilities for the metal cloud chemicals from the spacecraft. It is necessary to develop this aspect of the experiment to a high degree of reliability due to the inherent dangers of the process.

The main areas of development with respect to the RF heating experiment is that of a high-power RF transmitter and a remote maneuvering satellite.

6. References

1. W. I. Axford, J. Geophys. Res., 73, 6855, 1968.

2. J. W. Dungey, 1958 Cosmic Electrodynamics, Cambridge University Press, New York.

3. G. E. K. Lockwood, Can. J. Phys., 41, 190, 1963.

4. W. F. Ultand, J. Geophys. Res., to be published in 1970.

5. G. Haerendel, and R. Lust, Sci. Amer., 219, 81, 1968.

6. E. M. Westcott, et al., Trans. Amer. Geophys. Union, 50, 281, 1969.

7. D. F. Martyn, Nature, 183, 1382, 1969.

8. C. D. Florida, Proc. IEEE, 57, 6, 867, 1969.

9. W. Calvert, and J. R. McAfee , Proc. IEEE, 57, 6, 1089, 1969.

10. 4-PP-4, Alkali Metal Clouds--Formation of auroras.

4-PP-1, 2, 4, Remote Maneuvering Satellite

Critical Issues Addressed by Research Cluster
4-PP-3
THERMAL PLASMA IN THE IONOSPHERE AND MAGNETOSPHERE

4.1.6.4.3.2.1
1 Can the long wavelengths possible in space be used to study the nature of plasma waves?

4.1.6.4.3.2.2
1 Can alfven waves be propagated in the magnetosphere?

4.1.6.4.3.2.3
2 Can whistler-mode propagation experiments be performed in the magnetosphere?

4.1.6.4.3.2.4
1 Can drift waves be studied using the drift surfaces in the magnetosphere?

4.1.6.4.3.2.5
1 Can nonlinear waves be produced along lines of the force by injecting small-amplitude waves?

4.1.6.4.3.2.6
0 Is the bow shock similar to laboratory collisionless shocks? Are the dissipative mechanisms the same?

4.1.6.4.3.3.1
1 Can the Earth's magnetosphere be used to determine the deflection of electromagnetic waves in traversing a fluctuating plasma?

4.2.1.2.1.3.4.1.2
1 What is the electron density in the ionosphere?

4.2.1.2.1.3.4.1.3
1 What ionic species are present in the ionosphere?

4.2.1.2.1.3.4.1.3.1
1 What is the density of each ionic species present in the ionosphere?

---

[0] Related to research area but implementation would require expansion of the experimental techniques described herein.

[1] Related to research area but only partially answered by the experimental techniques described herein.

[2] Fully answered by the experiment techniques described herein.

4.2.1.2.1.3.4.1.3.2
1 What is the temperature of each ionic species present in the ionosphere?

4.2.1.2.1.3.4.1.4
1 What is the electron temperature in the ionosphere?

4.2.1.2.1.3.4.1.5
1 What waves are present in the ionosphere?

4.2.1.2.1.3.4.1.5.1
1 What effect does incoherent Cerenkov radiation have upon the level of observed ionospheric emissions?

4.2.1.2.1.3.4.1.5.2
1 How do VLF waves interact with naturally appearing and artificially produced charged particles in the upper ionosphere and magnetosphere?

4.2.1.2.1.3.4.1.5.3
1 How are VLF waves transmitted through the upper ionosphere?

4.2.1.2.1.3.4.1.5.4
1 How can artificially produced whistlers be detected from the ground and from other spacecraft, and how well correlate pertinent measurements with predictions of whistler theory?

4.2.1.2.1.3.4.2.1
2 Can chemicals be released into the ionosphere to alter significantly the local attachments and recombination rates, thus perturbing ionospheric characteristics?

4.2.1.2.1.3.4.2.2
2 What are the consequences of irradiating the ionosphere with high-intensity electromagnetic waves?

4.2.1.2.1.3.4.2.2.1
2 What RF power and frequencies are required to produce substantial heating of the ionosphere?

---

[0] Related to research area but implementation would require expansion of the experimental techniques described herein.

[1] Related to research area but only partially answered by the experimental techniques described herein.

[2] Fully answered by the experiment techniques described herein.

4.2.1.2.1.3.4.2.4
1 What are the processes determining the production and loss of ionospheric plasma?

4.2.1.2.1.3.5.2
2 How can the magnetosphere be investigated by the injection of low-intensity beams into the space plasma?

4.2.1.2.1.3.5.2.1
2 Can electron, proton, or plasma beams be injected into the magnetosphere to enhance naturally occurring instabilities?

4.2.1.2.1.3.5.4.3
1 Can electric fields exist parallel to the lines of force in the magnetosphere?

4.2.1.2.1.3.5.4.3.1
1 Is the conductivity infinite along lines of force in the magnetosphere, or do plasma instabilities impose a finite conductivity?

4.2.1.2.1.3.5.4.5
1 What are the fluctuating electric and magnetic field patterns in the Sunward portion of the Earth's magnetosphere?

4.2.1.2.1.3.5.4.5.1
1 What is the nature of transient fluctuations in the electromagnetic fields and the electron population?

4.2.1.2.1.3.5.4.5.2
1 Are electrons traveling in orderly fashion along lines of force, or are they being disturbed by fluctuating electric or magnetic fields?

4.2.1.2.1.3.5.4.6
1 What is the rọle of Bohm diffusion in the magnetospheric phenomena?

4.2.1.2.1.3.5.4.6.1
2 Is radial diffusion of trapped magnetospheric electrons driven by drift period resonances with magnetic oscillations, or by Bohm diffusion.

4.2.1.2.1.3.5.5
1 What waves can be propagated in the magnetosphere?

---

[1] Related to research area but only partially answered by the experimental techniques described herein.

[2] Fully answered by the experiment techniques described herein.

4.2.1.2.1.3.5.5.1

1 What are the dispersion relations in the magnetosphere?

4.2.1.2.1.3.5.5.3

1 Can ion cyclotron wave propagation experiments be performed in the magnetosphere?

---

[1] Related to research area but only partially answered by the experimental techniques described herein.

NO CREW ACTIVITY MATRIX DERIVED

FROM THIS CLUSTER (4 PP 3)

RESEARCH CLUSTER SYNOPSIS--SPACE PHYSICS
4-PP-4
Auroral Processes

1. Research Objectives

The aurora is one of the most obvious and striking manifestations of space physics phenomena. Its study and analysis dates back to earliest recorded history; in fact, one of the earliest explanations of auroral phenomena was advanced by Aristotle. Clearly, the study of the aurora falls within the broad NASA objective of obtaining a detailed understanding of the physical interactions and dynamic processes that determine the Earth's space environment.

It is now well established that the auroral optical displays result from the ionization and excitation of atmospheric constituents by energetic particles, both protons and electrons, and that the source of energy for these particles is the solar wind. The origin and processes that energize these particles are still not understood, nor are the factors that determine the wide variety of reproducible and regular precipitation patterns. Some aspects of the auroral problem are amenable to study at low altitudes. In fact, it is now apparent that some critically important processes occur in the altitude range below 1000 km. The objective of this research cluster is to study auroral phenomena that occur at low altitudes.

2. Background and Current Status

At low precipitated flux levels, the interaction between the precipitated particles and the upper atmosphere and ionosphere can probably be described by a simple collisional model. The intensity and altitude dependence of the observed optical emissions are in qualitative agreement with theoretical predictions. However, because of the uncertain, instantaneous nature of the atmospheric density and composition, and the lack of accurate knowledge of the precipitated particle flux and energy spectra, detailed comparisons with theoretical predictions have not been possible. The study of the interaction of low-intensity fluxes of known energy spectra constitutes one objective of the current program.

As precipitated fluxes increase in magnitude, collective interactions with the ionosphere become possible, resulting in modification of the energy spectrum of the precipitated fluxes and generation of plasma waves. Evans[1] has attributed his observations of 10-Hz modifications in the energy spectrum of precipitated electrons to such a collective interaction, and Perkins[6] has shown theoretically that a beam-plasma instability, as proposed by Evans, could occur at altitudes where the electron cyclotron frequency equaled the electron plasma frequency,

provided that the monoenergetic component[5, 8, 9] of the precipitated electron flux was sufficiently large. In order to explain the peculiar observed variation of precipitated energetic proton pitch angle distribution with altitude, Mozer[2] proposed the existence of a low-altitude electric field (20 mv/m) parallel to the magnetic field. Kennel and Kindell[10] have shown analytically that a region of anomalous resistivity along which an electric field can be developed can be produced in a collisionless plasma as a result of an ion wave instability. This instability is expected to develop at altitudes ~ 1000 km when the precipitate electron flux exceeds ~10^9 cm^{-2} sec^{-1}. Direct measurements of this parallel electric field using either barium cloud or Langmuir probe techniques have not provided definitive results to date. Lastly, Bernstein et al.[12] have observed impulsive enhancements in precipitated protons associated with decrements in the electron flux; these measurements indicate that the modifications must have been imposed at low altitudes.

The generation of artificial auroras through the injection of energetic particle beams from spacecraft-borne accelerators provides a technique for the study of these problems. Preliminary experiments have shown that optical intensities adequate for detection and spectral analysis can be attained from a rocket-borne electron accelerator. With proper programming of the precipitated particle energy spectrum, some characteristics of flaming or pulsating auroras may be simulated. In a corollary experiment, particle fluxes reflected from the conjugate point have been detected at the rocket. Thus, the validity of the beam technique for the study of atmospheric interactions and the topology of the magnetic field configuration appears to have been demonstrated. Extrapolation to the higher intensities required to develop collective effects and test the validity of the pertinent theoretical treatments represents another phase of this program. Such experiments may clarify the relationships between auroral observations and the open and closed topology of the pertinent field lines.

In a different context, Linsom and Petschek[7] have considered the role of crossed-field or Pederson conductivity of the ionosphere in auroral phenomena. In a collisionless plasma, the conductivity parallel to the magnetic field is always assumed to be good unless anomalous effects due to instabilities develop. In the absence of such instabilities, an increase in the cross-field conductivity due to an increase in electron density would short out electric fields that may develop perpendicular to the magnetic field. (This phenomenon is known as line tying.) Linsom and Petschek suggest that an increased crossed-field conductivity may trigger an aurora. Conversely, it is possible that a sudden decrease in the crossed-field conductivity might inhibit an already active aurora. The use of large barium clouds could produce the desired electron density enhancement, and clouds of SF_6, which has a high electron

attachment probability, could be used to attain the desired reduction in electron density. These experiments will permit an assessment of the coupling between high- and low-altitude processes that may play a fundamental role in auroral physics.

3. Description of Research

The triggering or halting of auroral precipitation by the creation of a large electron cloud by chemical means has been estimated to require 10^{24} electrons over a volume of 2×10^3 km^3 at a height of about 115 km in the auroral zone. The position of the spacecraft during this period would therefore be between L = 5 - 9 and at a height of about 500 km. The injection of the electrons would be accomplished by firing several rockets containing the chemical reactants simultaneously to the required altitude. Ideally, the use of multiple rockets together with turbulent diffusion would produce a fairly uniform electron density of $\sim 10^6$ cm^{-3} throughout the volume. The launching of the rocket could conceivably be performed from the space vehicle but as ground observation is required and due to the explosive nature of the chemicals, launching from the ground station seems more practical. The amount of material necessary to produce this number of electrons varies due to the different efficiencies of the processes. Linsom[7] estimates about 50 kgm of material is required for the method in which a mixture of cesium nitrate and aluminum in compressed form is burned; they estimate 300 kgm for an explosive process using alkali metals. The ideal material and process will therefore require more study as the unaffected portion of the material may seriously affect the desired results.

Observation of the cloud and the ambient plasma variations will ideally be accomplished from the ground and space laboratory. Measurements of the various particle fluxes and their energy distribution together with optical observations of the cloud and its resulting diffusion should be carried out by the space station. This will require a variety of particle detectors over an energy range of thermal to about 200 kev and optical observations will be made by photometers at specific wavelengths together with overall TV coverage.

The study of the effect of particle instabilities on auroral precipitation would be performed by the injection of large fluxes of particles down field lines from the space laboratory. The space vehicle would be in the L = 5 to 9 region at a height of about 600 km. The instability growth will be studied as before from onboard the space vehicle and at convenient ground stations simultaneously. In the case of the plasma instabilities described by Perkins, the electron beam energy would be 10 kev. The required theoretical flux[6] for particle acceleration is estimated to be of the order of 10^{10} electrons cm^{-2} sec^{-1} str^{-1} which should be injected over as wide an area as possible and at various pitch angles. Variations in duration of the bursts should be performed

in order to study growth and decay processes associated with the instability. Measurements of particle fluxes and energy distribution should be completed over a thermal to 200-kev energy range together with local measurements of any ac electric and magnetic fields and x-rays produced. The effect of various beam plasma instabilities could be carried out for protons and electrons as a function of particle energy, flux, and pitch angle.

4. Impact on Spacecraft
This experimental cluster requires that the space laboratory spend the maximum possible time in the region of L shells 5 to 9, which indicates either high inclination or polar orbits. In terms of manned operation it is more desirable that the minimum amount of exposure to the radiation inherent to this region occur. Therefore a compromise orbit covering the lower L shells to about L = 6 is more practical. The launching of the chemical reagents on rockets from the space laboratory for the triggering of an aurora does not appear feasible due to inherent dangers. On the other hand the launching of small amounts of material to perform electric field measurements at high altitudes during an induced aurora from the space vehicle may be quite practical. If launching from the vehicle is required, safe storage of the reagents and launching facilities will be necessary. The diagnostic requirements will be compatible with the diagnostics listed for the other research clusters and it appears that little specific new development is necessary. This also applies to the particle beam experiments discussed as they are directly related to the apparatus used in the energetic particle cluster (4-PP-2). Typical experiments would require the appropriate physicist and an electromechanical technician.

5. Required Supporting Technology Development
The major requirement for technological advances are in the framework of the formation of electron clouds to produce and halt auroral precipitation. The yield from the majority of the processes is of the order of a few percent and therefore especially in the case where large amounts are necessary, payload weight is a problem. Also, problems may occur due to the effect the non-reacting elements of the cloud will have on the local plasma and the electron cloud.

On the subject of beam instabilities, theoretical development is necessary to clarify the propagation characteristics of energetic particle beams in space. This will ideally be pursued in conjunction with the development of particle acceleration systems producing large beam currents over a wide energy range.

6. References

1. D. S. Evans, J. Geophys. Res., 72, 4281, 1967.

2. F. S. Mozer, and P. Bruston, J. Geophys. Res., 71, 2201, 1966.

3. R. D. Albert, paper presented at the Conference on Electric Fields in the Magnetosphere, Rice University, Houston, Texas, 1969.

4. Bryant Et al., J. Atmospheric and Terrestrial Physics, 31, 579, 1969.

5. D. S. Evans, J. Geophys. Res., 72, 2315, 1968.

6. F. W. Perkins, J. Geophys. Res., 73, 6631, 1968.

7. L. M. Linsom, and H. E. Petschek, Report on Ad Hoc Committee on Environment Modification Experiments in Space, Univ. Maryland, 1968.

8. E. C. Mc Ilwain, J. Geophys. Res., 65, 2727, 1960.

9. R. D. Albert, Phys. Rev. Letters, 18, 369, 1967.

10. C. Kennel, and J. Kindel, private communication, 1970.

11. 4-PP-2, Energetic Particle Dynamics in the Magnetosphere.

12. W. Bernstein and R. L. Wax, J. Geophys. Res., 75, 3915, 1970.

Critical Issues Addressed by Research Cluster

4-PP-4

AURORAL PROCESSES

4.1.6.3.1.1.2
2 Are the end-plate precipitation patterns observed in mirror machines in any way analogous to precipitation patterns observed in the aurora?

4.2.1.2.1.3.3.1
1 To what extent do the Earth's ionosphere and magnetosphere affect the fractionation and balance of hydrogen and helium in the Earth's atmosphere?

4.2.1.2.1.3.4.2.3
2 Can the ambient electron density in the lower ionosphere at auroral latitudes be sufficiently enhanced to trigger an aurora?

4.2.1.2.1.3.4.2.5
2 Can an artificial aurora be produced by the injection of high-energy particles from a spacecraft? Which diagnostics are required to relate such an artificial aurora with a natural one?

4.2.1.2.1.3.5.6
2 Are striations a characteristic of the space environment? Is the Simon theory valid?

---

[0] Related to research area but implementation would require expansion of the experimental techniques described herein.

[1] Related to research area but only partially answered by the experimental techniques described herein.

[2] Fully answered by the experiment techniques described herein.

NO CREW ACTIVITY MATRIX

DERIVED FROM

THIS CLUSTER

(4 PP 4)

RESEARCH CLUSTER SYNOPSIS—SPACE PHYSICS 4-CR-1 Charge and Energy Spectra of Cosmic-Ray Nuclear Components

1. Research Objective

The goal of this research is to determine the charge composition of the nuclei that make up the greatest part of the high-energy cosmic-ray flux, and to determine the energy composition of each of the components. Knowledge of the composition is praticularly important because this gives us a sample of the universe outside the solar system. For the energy range accessible to observation by satellite instrumentation (below 10^{15} eV), cosmic-ray particles will be confined to the galaxy by the local magnetic field. Cosmic-ray primaries with energies up to 10^{20} eV have been detected. These are of great interest because they are presumed to arrive from outside the galaxy; however, their flux is too low (10^{-7} m^{-2} $ster^{-1}$ $year^{-1}$ at 10^{20} eV) for determining their properties in a satellite experiment.

On the low-energy side, we are limited by the terrestrial and solar magnetic fields. For a near-earth satellite in near-equatorial orbit, the practical lower limit is about 1 to 10 GeV per nucleon. Extensive data are also available below 1 GeV per nucleon, but very few measurements on individual species are available above 10 GeV per nucleon. An extension of the present measurements to higher energies would give valuable information on those elements, which may be responsible for the production of the cosmic-ray primaries and the modification of their properties as they pass through the galaxy. These include supernovae, pulsars, and quasars, and the distribution of matter and magnetic fields.

The composition of the primary cosmic radiation is modified by collisions with the interstellar gas. These collisions result in spallation of the heavy nuclei. A study of the spallation products gives information on the distance the cosmic rays have travelled, and hence on their age.

In addition to the studies of energy spectrum and charge composition, we have suggested a study of the isotopic composition of the low-Z elements. The ratios D:H and He^3:He^4 will give independent information on the production, acceleration, and transmission of the cosmic-ray primaries.

The discovery of Be^{10} and the measurement of its spectrum at high energies would be of particular interest. This nuclide is radioactive, with a mean life of 4×10^6 years in its rest frame. In the energy range we are considering, above 10 GeV per nucleon, the effect of relativistic time dilatation is important.

A measurement of the energy spectrum up to 100 GeV per nucleon, for instance, would give us a range of mean lives from 4×10^6 to 4×10^8 years. This compares to the estimated mean age of the cosmic rays (below 10 GeV per nucleon) of 2×10^6 years if they are confined to the galactic disc, and more if they spend a good part of their time in the halo. We would therefore have a new source of information on the structure of the galaxy.

2. Background and Current Status

An excellent summary of the present status of cosmic-ray research has been given by Peter Meyer.[1] References to the original publications can be found in this work.

A number of experimenters have measured the flux and energy spectrum of protons in the range from 20 MeV to 10 GeV, and of helium nuclei from 15 MeV per nucleon to 30 GeV per nucleon, and results have been consistent. Over roughly the same energy range, data are available on the flux of Be, B, C, N, O, Ne, Mg, Si, and the group $16 \leq Z \leq 30$. Above 10 GeV per nucleon, the data on the energy spectrum of individual species are sparse.

The energy spectrum of the total cosmic radiation, however, is known to about 10^{20} eV. At the highest energies, the results of measurements on extensive air showers are used. Only the secondary particles are seen, and it is difficult to infer anything about the primary except for its total energy. Up to 10^{15} eV, the differential spectrum has the form.

$$j(E) \sim E^{-\gamma}$$

where $\gamma = 2.6$. Between 10^{15} and 10^{18} eV, the spectrum steepens, with $\gamma = 3.2$. Above 10^{18} eV, there are indications that the spectrum flattens again. The integral flux, particles of energy greater than E per (m^2 sec sterad), has the values 0.3 at 10^{12} eV, 10^{-7} at 10^{16} eV and 10^{-15} at 10^{20} eV.

The relative abundance of low-energy nuclei (about 100 MeV per nucleon) has been measured up to $Z = 16$ for individual species, and for the groups P-K, Ca-Cr, and Mn-Ni (the Fe group). When this is compared with the estimated universal abundance of the elements, the agreement in most cases is good. The most notable discrepancy is the high frequency of $Z = 3$ to 5 in the cosmic rays. This occurs about as often as Si, whereas in Cameron's table of universal cosmic abundancies, the numbers relative to Si are: Li, 4.5×10^{-5}; Be, 7×10^{-5}; B, 6×10^{-6}.

The excess in the range $Z = 3$ to 5 is thought to result from the spallation of higher -Z nuclei, in their passage through 3 to 5 g/cm^2 of hydrogen. If we take the density of interstellar gas to be one H atom per cm^3, the mean time that the cosmic rays

have spent in the galactic disc is 2×10^6 years. The abundance of fluorine is consistent with this estimate.

At higher energies, the charge spectra are in general similar to those measured at ~100 MeV per nucleon. In the range Z = 16 to 28 (S to Ni), the chemical composition of relativistic nuclei (above 1.58 GeV per nucleon in one case and 7 GeV per nucleon in the other) has been measured with sufficient resolution to distinguish the individual species.

Recently, cosmic-ray nuclei with $Z > 30$ have been found. The charge spectrum covers the whole periodic table. Four tracks have been found with $Z > 80$, and of these, one appears to have a charge of about 106. The frequency of these tracks is very low; all nuclei with $Z > 30$ amount to about 10^{-4} of the Fe group.

As far as the isotopic composition of the primaries is concerned, data are available for only hydrogen and helium. The flux of deuterons has been measured in the neighborhood of 50 MeV per nucleon where it is about 5 percent of the proton flux. The He^3:He^4 ratio is about 0.1 between 100 and 300 MeV per nucleon, and lower at lower energies. The terrestrial ratios are 1.5×10^{-4} in both cases. No data are available at higher energies, nor for any other elements.

3. Description of Research

The three types of instruments used to determine the charge and energy of high-energy particles would be:

1. Proportional, scintillation Cerenkov counters to measure Z^2 F(v).

2. Magnetic spectrometers to measure momentum per Z.

3. Total energy counters.

For relativistic particles, any two of these measurements will be sufficient to determine charge and energy, provided we assume that we know the ratio of mass to charge. To measure isotopic abundance, all three measurements are required. We shall therefore assume that both a large magnet and a total-energy spectrometer are available.

The exact combination of counters will depend on the details of the measurement. In general, we envision a set of (minimum-mass) multiwire spark or proportional counters to determine the path of the particle through the magnetic field, followed by a dE/dx counter and then a total-absorption counter to measure the energy. A measurement with this set of instruments will give an overdetermined result, and hence a consistency check. It will also give the direction of the incoming particle, so that the isotropy of the radiation can be determined if the counters are oriented to sweep out a significant part of the sky.

4. Impact on the Spacecraft

Two of the instruments—the superconducting magnet and the total energy spectrometer—will have a significant impact on the spacecraft.

The magnetic moment of the superconducting magnet will be of the order of 10^6 amp-m^2. If it is oriented at right angles to the Earth's magnetic field, the torque will be several hundred foot-pounds. This torque will have a large impact on the orientation system, and will have to be taken into account in the initial design of the spacecraft instead of being treated as a perturbation. A possible solution to this problem is the incorporation of a pair of superconducting magnets within the cryostat. This would require greater cooling capacity from the spacecraft along with increased weight. Such an arrangement, however, would eliminate the need for a reactive torquing system. Moreover, two magnets m might prove useful in the laboratory design since many of the experiments in the other cluster make use of a magnetic spectrometer.

The superconducting magnet must be kept at or near the temperature of liquid-helium at all times. This will require the spacecraft to have a cryogenic system designed for this purpose. Total-absorption spectrometers that have the necessary number of nuclear mean-free paths are large and heavy. A total-absorption detector for this experiment cluster can be expected to weigh up to 24,000 pounds, and even greater.

5. Required Supporting Technology Development

Large superconducting magnets for space applications are presently under development (e.g., by Alvarez). The development of these magnets and a suitable cryogenic system are required for several research clusters.

Total-absorption spectrometers have been developed by several groups, and we foresee no insoluble problems in this area.

Spark chambers with a resolution of a few tenths of a millimeter are available. An improvement by an order of magnitude in the resolution would result in a corresponding improvement in the spectrometer resolution. This requirement may be filled by liquid xenon proportional counters, which are presently under development.

6. References

1. Peter Meyer. Annual Review of Astronomy and Astrophysics, Vol. 7, 1969.

Critical Issues Addressed by Research Cluster

4-CR-1

CHARGE AND ENERGY SPECTRA OF COSMIC RAY NUCLEAR COMPONENT

4 2.1.3.3.2.2.1 2.1
What is the abundance of the low-mass isotopes present in cosmic radiation?

4.2.1.3.3.2.2.1.2.2
What is the charge composition as a function of energy of the primary cosmic radiation?

4.2.1.3.3.2.2.2.4
What is the energy spectrum of protons in the primary cosmic rays?

4.2.1.3.3.2.2.2.5
What is the energy spectrum of the light nuclei in the primary cosmic radiation?

4.2.1.3.3.2.2.2.5
What temporal fluctuations are present in the nuclear component of the primary cosmic-ray flux?

4.2.1 3.3.2.2.3.4.
What is the degree of anisotropy present in the nuclear component of the cosmic-ray flux?

RESEARCH CLUSTER SYNOPSIS—SPACE PHYSICS
4-CR-2
Energy Spectrum of the High-Energy Primary Electrons and Positrons

1. Research Objectives

The objective of this research cluster is to determine the properties of the electron-positron component of the primary cosmic radiation. These properties include the flux and energy spectrum, the directional distribution, and the electron-to-positron ratio as a function of energy. The directional distribution is probably important at only the very highest energies, because of the deflection of charged particles in terrestrial, solar, and galactic magnetic fields.

The results will be used to test the validity of theories of the origin of the cosmic radiation, and of the diffuse x-ray background.

The use of a space station is required for this experiment for two reasons: (1) to get above the effects of atmospheric attenuation and (2) to obtain the long observation times requires for low-counting-rate experiments.

2. Background and Current Status

Primary electrons are thought to be generated by two different processes: by acceleration of low-energy electrons, and as secondaries from the nucleonic-component collisions of the cosmic radiation. These electrons are removed from the cosmic-ray population by the processes that affect the nucleons; there are also processes that depend on the particle mass and which are much more effective for electrons than for protons. These include the Compton effect and synchrotron radiation in ambient magnetic fields. As a result of these processes, the primary electron flux at a given energy is about 1 percent of the proton flux.

Approximately equal numbers of electrons and positrons result from nuclear reactions (e.g., by $\pi^{\pm} \rightarrow \mu^{\pm} \rightarrow e^{\pm}$ decay), and the principal removal mechanisms are equally effective for the two signs of charge. If all cosmic-ray electrons were secondaries from the nuclear component, we would expect to find equal mumbers of positrons and electrons. Measurements, however, show that there are about ten times as many electrons as positrons, at least between 0.5 and 10 GeV. The conclusion is that the bulk of electrons is directly accelerated.[1]

The electron spectrum is fairly well known from 2 MeV to 300 GeV.[1] The positron spectrum is much less well known. There are two reasons for this: (1) the lower intensity of

positrons, and (2) the difficulty of determining the sign of the charge. Better knowledge of this flux and spectrum would provide valuable data bearing on the production process, the lifetimes, the storage of the electron component, the energy density of photons in the galaxy, and the galactic magnetic field.

3. Description of Research

The object of this research is to obtain accurate data on the flux and spectra of cosmic-ray electrons and positrons over as great an energy range as possible. The lower limit to the energy range will be a few GeV, if the spacecraft is in low Earth orbit: the limit is due to the Earth's magnetic field.

A typical experimental arrangement would consist of a large superconducting magnet, a set of multiwire spark chambers to define the path of the particle through the magnetic field, a total-energy counter in which the energy of the electromagnetic shower is measured, and a set of counters to trigger the system. With a magnetic field of 1 tesla and spatial resolution of a few tenths of a millimeter, the charge of the incident particle can be determined up to a momentum of about 3×10^{11} eV/c.

The flux of protons is three orders of magnitude higher than the expected positron flux. It will therefore be necessary to identify positrons with a high degree of certainty. This will be done by following the shower development in detail in the total-energy counter.

4. Impact on Spacecraft

In common with several other areas of research, the investigation described here will require a large superconducting magnet. The interaction of this magnet with the Earth's field will produce a torque, which will have a substantial effect on the orientation system of the spacecraft. It will also require a cryogenic system capable of maintaining the magnet coils continuously at, or close to, liquid helium temperature.

The weight of the total-energy counter will be of the order of 1 ton. This could be reduced somewhat at the expense of a loss in counting rate.

To make possible the identification of high-energy positrons, the space available for the experiment should have dimensions of several meters. We anticipate that a series of experiments will be grouped around the magnet, all taking data simultaneously. If this is so, the addition or deletion of this one experiment would not have a large impact on the spacecraft.

5. Required Supporting Technology Development

The most important item of equipment is the superconducting magnet. Magnets of this type have been built, and work is continuing on design improvement. The cryogenic system for the spacecraft will require development.

Spark chambers with 0.1-mm resolution are presently available, and liquid argon or xenon chambers with improved resolution are under development. Both will be adequate for the experiment. Total-energy counters have been designed, and no major problems are foreseen in this area.

6. References

1. Peter Meyer. Annual Review of Astronomy and Astrophysics. Vol. 7, 1969, p. 1.

Critical Issues Addressed by Research Cluster

4-CR-2
ENERGY SPECTRUM OF HIGH-ENERGY
PRIMARY ELECTRONS AND POSITRONS

4.2.1.3.3.2.2.1.1.1
What is the electron-position ratio in the primary cosmic radiation as a function of energy?

4.2.1.3.3.2.2.2.3
What is the energy spectrum of the primary electrons in the cosmic rays?

4.2.1.3.3.2.2.3.2
What is the spatial and temporal distribution of electrons in the primary cosmic-ray flux?

RESEARCH CLUSTER SYNOPSIS—SPACE PHYSICS
4-CR-3
Energy Spectrum and Spatial Distribution of Primary Gamma Rays

1. Research Objectives

Study of the incident flux of primary gamma rays can lead to the solution of some of the most fundamental problems of astrophysics, such as the presence of antimatter in the universe (discussed in research cluster synopsis 4-CR-5), the properties of galactic and intergalactic matter and magnetic fields, and the general question of the origin and nature of discrete cosmic-ray sources. The full NASA Astronomy Review Board reviewed the gamma-ray experimental situation and concluded that "gamma radiation in the 10-MeV region of the electromagnetic spectrum is a particulary important problem in cosmology . . ."

It should be pointed out that weak sources of gamma radiation must be detected above the atmosphere because the atmosphere itself provides a background of >50-MeV γ-rays of $\sim 10^{-3}$ cm^{-2} sec^{-1} sr^{-1} per millibar of residual atmosphere, a flux that limits the sensitivity of any balloon-borne experiment. Furthermore, the low-background rates achievable in space point to the need for a long observation time with large area detectors to obtain statistically significant data. These experimental requirements can be met with the Space Station's cosmic-ray laboratory.

2. Background and Current Status

Gamma-ray sources can be grouped into two broad categories, diffuse and discrete. Examples of the former are the interstellar and intergalactic mediums; examples of the latter are x-ray stars, supernovae (or their remmants), and possible quasars or pulsars.

The primary production mechanisms for the diffuse gamma rays are (1) inverse Compton scattering of high-energy electrons with the ambient 2.7 °K black body radiation or with starlight, (2) decay of π^0 mesons that have been produced in either nucleon-nucleon collisions or matter-antimatter annihilation, (3) synchrotron radiation, and (4) bremmstrahlung. The strength of these four mechanisms depends on many properties of the galaxy, as well as intergalactic space. For example, gas magnetic field, starlight density, the presence of antimatter, and the spectrum of protons and electrons in the primary cosmic rays all affect the gamma-ray source mechanisms and therefore the gamma-ray spectrum.

Experimental searches for cosmic gamma rays began in 1959. Outside the galactic plane, measurements exist only for energies up to 6 MeV; above this energy, only upper limits exist for the flux except for an integral measurement at 100 MeV. The results

are difficult to interpret although various explanations have been made for the observed spectrum shape, a spectrum that becomes flatter as the energy increases above 1 MeV. One of the spectral features expected is a peak near 70 MeV, resulting from the decay of π^0 mesons. These mesons would be produced either by nucleon-nucleon collisions or matter-antimatter annihilations, and the spectral shape will determine which source predominates. If the π^0 mesons are produced at cosmological distances, the 70-MeV peak will be shifted to lower energies because of the red shift. This has led to the interesting suggestion of a red shift of 10 or greater to explain the observed gamma-ray spectral flattening.[1]

Diffuse high-energy gamma rays were also measured in the galactic plane by Clark, et al.[2] Their results were consistent with a line source of photons along the galactic plane, with the strongest sources at the galactic center. Since the resolution of their detector was ±15 degrees, it was not possible to determine whether the source was indeed diffuse, or represented a number of discrete sources.

The only measurement to date of a discrete high-energy gamma-ray source was made in 1969 by Frye, et al.[3] The evidence for this source in the vicinity of Sagittarius is not as strong as that for the galactic component, since this source has not been verified by any other group.

As can be seen from this brief survey of available experimental results, much important work remains to be done in the areas of source identification and spectrum determination of the primary gamma rays. With these measurements, along with the results from most of the other experiments in the cosmic-ray laboratory, answers to many of the fundamental questions of cosmic-ray origin and properties of interstellar and intergalactic space can be answered.

3. Description of Research

Only the high-energy gamma-ray portion of the electromagnetic spectrum is being studied as a part of cosmic-ray physics; the lower-energy portions of the spectrum are being investigated as part of Space Astronomy. This division is quite natural on the basis of experimental techniques and equipment; the facility defined for the other cosmic-ray clusters is easily reconfigured for the study of high-energy gamma rays; that is, the techniques for detecting this radiation are those of particle detection and counting normally used in a cosmic-ray experiment.

For neutral particles to be detected, they must first interact to produce charged particles. High-energy gamma rays are detected through their production of electron-positron pairs in a converter. The direction and energy of the incident photon is then determined by analyzing the trajectory and energy of the pair produced.

One possible technique for analyzing this production process is the use of multiplate spark chambers. With the present state of instrument development, spark chambers are probably the best possible choice for a detector since they (1) can be postevent triggered, and (2) have high spatial resolution, about 0.1 mm. The former requirement is necessary because the detector must be triggered after the particle passes through a set of coincidence detectors; the latter requirement is necessary whenever directional information is needed. In addition to the converting spark chamber, the superconducting magnet could be used to provide a measure of their energy. To define the trajectory through the magnet, additional spark chambers would be required and an array of scintillators in coincidence would be used to trigger the spark chambers.

A major problem encountered in performing this experiment is that of separating the desired component from the unwanted background radiation of other particles, particularly neutrals created through interactions of the incident cosmic-ray flux with the space station. By placing the converting spark chamber within an anticoincidence shield (except for the direction in which the created pair will leave the chamber), the charged particle background will be substantially reduced. To prevent backward-going particles from unnecessarily triggering the spark chambers, time-of-flight techniques could be used with the scintillation coincidence circuitry. The shower that develops in the total-absorption shower cascade counter (TASC) will be an electromagnetic one, and therefore distinguishable from one caused by mesons or nucleons.

The experiment should look directly out into space to minimize background, and both scan and fixed pointing modes are anticipated in searching the sky for new sources and then studying them when found, as well as making measurements of the diffuse sources.

4. Impact on Spacecraft

As has been pointed out above, the instrumentation required for this experiment is essentially the same as that being used for the other experiments, except in a somewhat different configuration with different electronic logic. One impact of this experiment not present in the others, however, is the requirement for directional alignment. Thus this experiment should be capable of being pointed at a specific region of the sky within 0.1 degree, or better, and also of slowly scanning both on and off the galactic disc.

As in most of the other experiments, the background should be kept to a minimum, which requires that the spacecraft orbit be well outside the radiation belts. During passage through the South Atlantic anomaly, excessive background will make the experiment inoperative.

The initial setup and checkout would be performed by the astronaut with the aid of an onboard computer for automatic setting and testing of the logic sequence and signal trigger levels. The experiment data from the various counters and the TASC would be digitized and placed in computer storage for later transmission. Once the experiment had been set up, aligned, and calibrated, it should be run continuously with automatic periodic testing and calibration. The data must be presented as a function of angular position while in the scan mode. When in the fixed direction mode, the experiment would be run until statistically significant results were obtained, and a different pointing direction would then be chosen.

5. Required Supporting Technology Development

Except for the development of the superconducting magnet system and of total-absorption counters as described in 4-CR-2, no additional work is required. If special resolution detectors capable of better than the 0.1 mm attainable with spark chambers are developed, they would improve the angular resolution of the experiment; indeed, such detectors, which again must be post-event triggerable, would be useful for any of the experiments that require information about particle trajectories.

The details of the timing sequences and detector geometry must be worked out, but the problems are well understood and the solutions will be derived as a part of a detailed experiment configuration description.

6. References

1. F.W. Stecker. Nature 224, 870 1969, p. 870.

2. G.W. Clark, G.P. Garmire, and W.L. Kraushaar, Proceedings of the IAV Symposium, No. 37, edited by L. Gratton, Rome, 1969.

3. G.G. Frye, Jr., J.A. Starb, A.D. Zych, V.D. Hooper, W.R. Rawlinson, and J.A. Thomas. Nature 223, 1320 1969, p. 1320.

Critical Issues Addressed by Research Cluster

4-CR-3
ENERGY SPECTRUM AND SPATIAL DISTRIBUTION
OF PRIMARY GAMMA RAYS

4.2.1.3.3.2.2.2.1
What is the energy spectrum of gamma radiation present in the primary cosmic-ray flux?

4.2.1.3.3.2.2.3.3
What is the spatial and temporal distribution of gamma rays in the primary cosmic ray flux?

RESEARCH CLUSTER SYNOPSIS—SPACE PHYSICS
4-CR-4
Long-lived Heavy Isotopes in Cosmic Rays

1. Research Objectives
The experiments for this research group are directed toward the detection and identification of the very very heavy (VVH) isotopes that are present in the primary cosmic radiation. These particles have very short interaction lengths and attempts to detect these particles with balloons have only indicated that such particles are indeed present in the incoming radiation, and in greater abundance than predicted by universal abundance compilations. Thus, experiments to detect these VVH primaries would benefit greatly from being performed onboard a space platform. In line with the Space Physics goals in L13-9852, such experiments will prove the value of a laboratory in space in general, and more concretely, will form an important part in determining the character of galactic cosmic rays.

It should be noted that, in addition to the elimination of the atmosphere as an unwanted interaction medium that is a part of every balloon experiment, the spacecraft will provide much longer observation times than is possible with a balloon. This advantage will mean that the duration of experiments in a cosmic ray laboratory can be determined more by the requirements of the experiment than by the capability of the vehicle.

2. Background and Current Status
Recent theoretical calculations[1] based on the shell model of nuclei have led to the prediction that islands of stability exist in the nuclides with neutron numbers near 184 and with atomic numbers near 126. Both of these numbers are "magic," i.e., shell model calculations predict exceptional stability for nuclides containing this number of neutrons or protons. The most stable of these nuclei is predicted to be $_{110}X^{294}$ with a half life as large as 10^8 years. Other nuclei in this island have predicted half lives of up to 10^4 years. These predictions are quite uncertain and there is even doubt as to which nuclei are the most stable.

As yet there have been no quantitative calculations as to how such nuclei could be formed, although the r-process of rapid neutron capture in supervnoae would be the most probable mechanisms for these nuclei.

A second objective of this cluster is to measure the isotopic abundances and rigidity spectra of the transuranic nuclei present in the cosmic ray primaries. By studying the relative abundances of radioactive nuclei with charge 90 to 96 important information regarding propagation time of cosmic rays within the galaxy will be obtained. In particular, the elements $_{93}Np$, $_{94}Pu$ and, $_{96}Cm$

have lifetimes in the range from 10^6 to 10^8 years, the suggested lifetimes of the cosmic rays themselves. By measuring the abundances of these elements, the much more difficult requirement for isotope measurements can be circumvented in obtaining cosmic ray lifetime measurements.

In addition to cosmic ray lifetime determinations, the measurement of the relative abundance of the uranium group ($90 \leq Z \leq 96$) to the lead group ($Z \geq 82$ or 83) can give a measure of the gas density over the cosmic ray propagation distance.

Experimentally, primary cosmic ray nuclei have been measured near the top of the atmosphere with balloon borne instrumentation. Fowler, et al., (1967)[2] and Fowler (1969)[3] used nuclear emulsions as detectors while Blanford et al., (1969)[4] used nuclear emulsion—plastic track detector sandwiches. To date the total exposure of all these detectors is 8×10^3 m^2 sr hr, and only as an integral flux above 4.5 GV. In total, three particles with charge greater than 96 may have been observed. There is an uncertainty in the charge of these nuclei since different values were obtained with emulsions than were obtained with the etched plastic. Thus additional measurements, such as would be possible on a spacecraft with large area detectors, are needed to deter- both the charge spectrum and rigidity spectrum of these rare cosmic ray particles.

3. Description of Research

Several experimental techniques can be utilized for identifying an incoming cosmic ray particle as transuranic. As with the experiments of Fowler, et al., nuclear emulsions could be flown, exposed to the incident flux, and later developed. A second technique consists of exposing plastic sheets to the incoming radiation and then etching these sheets to make the particle tracks distinguishable. The plastic detectors have two decided advantages over the emulsions for this investigation. First, the response of emulsions will allow only identification of transuranic nuclei differing by as little as one charge unit. Secondly, the plastics are many orders of magnitude less sensitive to background radiation than are emulsions.

However, the absolute sensitivity of the etched plastic sheets is difficult to determine. Thus, a better arrangement is a stack consisting of both types of detectors thereby permitting an intercomparison between the tracks in each of them due to a single particle. A second possibility, although less reliable, is to depend on collecting many events so that abundance peaks could be identified by plausibility arguments.

The possible counter experiment which would measure the mass directly could consist of the usual triggering logic and spark chambers plus a transition radiation detector for velocity measurement and a TANC detector to measure the energy. Such

an experiment presupposes that such devices can be built with sufficient size and geometry factor that some reasonable event rate would result from the extremely small predicted flux.

Another technique that has been proposed is the use of a large-area system consisting of ionization counters and Cerenkov counters. Both ionization and Cerenkov radiation are functions of the charge of the incident particle, but with differing velocity dependence. By using the counters in combination, it is possible to identify the charge of the incident primary within the limits imposed by the measurement errors and the statistical nature of the processes involved in the counter techniques.

For the latter type of counter experiment, the detectors would be set up, aligned and calibrated. Electronic thresholds would be determined for the detector electronics and the coincidence circuitry set, possibly through the use of an onboard computer. Each incident particle satisfying the computerized experiment logic would be accepted and the data digitized for storage and/or transmission. The experiment would run continuously until sufficient data statistics had been accumulated to permit the abundancies of the nuclei to be determined.

4. Impact on Spacecraft

The use of an emulsion-plastic detector sandwich for this experiment would place no requirements on the space vehicle for either data or power. However, the emulsions must be kept within the temperature range from 2 to 25°C, not a stringent requirement. A more serious problem for the emulsions is their sensitivity to background radiation, including cosmic ray protons and trapped electrons, the latter of which could be the more serious depending on spacecraft orbit. For example, at a 270 nmi, 55 degree orbit, the emulsions would be fogged in three days. Thus a lower equatorial orbit is highly desirable for this experiment, in which case the emulsions could be unshielded and remain operationally exposed for up to three months.

The emulsion-plastic sandwiches should be stored in a shielded container before use and then placed outside the spacecraft for exposure. Thus an astronaut is required to emplace the sandwiches in the natural space environment, and the, after exposure, remove them for storage, or, if possible, onboard development. (By developing the emulsions onboard, the necessity of reshielding the exposed plates is eliminated.)

The detector arrays will be on the order of several square meters of area and, if shielded, weigh about 200 pounds per square meter.

If an ionization-Cerenkov counter experiment is used, an astronaut would be required initially for set up and calibration, and

later for periodic calibration checks, although computerization might eliminate the latter requirement. An estimate of spacecraft requirements for a sample experiment is as follows:

Weight	1,500 lb
Power	70 w
Telemetry	2 Kb/sec.

If the more ambitious experiment using a transition radiation detector and a TANC detector is used, then there would be very little additional weight, power and telemetry requirements for this experiment over what is required for the laboratory as a whole. Again, however, astronaut time would be required for initial setup, testing and calibration procedures.

5. Required Supporting Technology Development

The use of emulsions is well developed for determining particle identities. However, improvements in reducing the effects of background radiation would be helpful, although how this could be achieved is difficult to conceive since at present the emulsions must be sensitive to electrons so that the number of delta rays can be counted to determine the primary particle's charge. Improved calibration procedures for plastic detectors are also required before absolute particle charge determinations can be made.

For the counter experiment, the development of a transition radiation detector would greatly aid in determining the velocity of the incident particle. These detectors are based on the principle that when a charged particle crosses a dielectric boundary it emits electromagnetic radiation extending to the x-ray region. Experimentation is being performed to devise a workable system to detect this radiation although at present nothing usable is available.

6. References

1. S.G. Nilsson, C.F. Tsang, A. Sobiczewski, Z. Szymanski, S. Wycech, C. Gustafson, I-L. Lamm, P. Moller, and B. Nilsson, On the Nuclear Structure and Stability of Heavy and Superheavy Elements, Nuclear Physics A131, 1, (1969).

2. P.H. Fowler, R.A. Adams, V.G. Cowen, and J.M. Kidd, Proc. Roy. Soc. (London), Ser. A 301, 39 (1967).

3. P.H. Fowler, XI International Conference on Cosmic Rays, Budapest, paper OG-79, (1969).

4. G.E. Blanford, Jr., M.W. Friedlander, J. Klarmann, R.M. Walker, J.P. Webel, W.C. Wells, R.L. Fleischer, G.E. Nichols, P.B. Price, Phys. Rev. Letters 23, 338 (1969).

Critical Issues Addressed by Research Cluster

4-CR-4
LONG-LIVED HEAVY ISOTOPES IN COSMIC RAYS

4.2.1.3.3.2.2.1.3.2
Are there any long-lived heavy isotopes present in the cosmic rays?

4.2.1.3.3.2.2.1.3.3
Are there any stable neutron-rich transuranic elements present in the cosmic radiation?

RESEARCH CLUSTER SYNOPSIS—SPACE PHYSICS
4-CR-5
Antinuclei in Cosmic Rays

1. Research Objectives

The prime objective of this research cluster is the detection of antinuclei in cosmic rays. Their discovery would have profound astrophysical significance in that the presence of antimatter, particularly antihelium, in cosmic rays would almost certainly prove the existence of antimatter stars. The very real possibility of antimatter galaxies would also be suggested by this discovery.

The search for these nuclei must be performed from a spacecraft because: 1) incident antinuclei would annihilate with the nuclei in the atmosphere; 2) the fluxes are expected to be quite small, so that long counting times are required; and 3) a fairly complex and heavy experimental setup will be required to unambiguously detect the presence of an antinucleon in the incident flux.

Thus, the development of an experiment in this area satisfies two broad objectives—utilization of the space vehicle's unique capability for experimental investigations, and provisions of answers to fundamental questions in cosmic ray physics and in cosmology and astrophysics.

2. Background and Current Status

With the first prediction and discovery of the positron, physicists and philosophers alike predicted the existence of other antiparticles. The antiproton and antineutron were discovered with the aid of large accelerators. Similarly, other antiparticles have been discovered, so that the symmetry between particles and antiparticles has become one of the fundamental principles of physics. The natural extension of this principle, at least on philosophical grounds, is the existence of equal amounts of matter and antimatter in the universe, i. e., in total, the net baryon count in the universe should be zero.

Should such be the case, several questions immediately arise. Where is all the antimatter? What keeps it from annihilating with the matter? How, if it exists, can it be detected? The last of these questions is the only one that has been experimentally investigated so far without positive results. The search for these particles centers on the primary cosmic rays.

The observation of even a few antinuclei in the incident cosmic radiation would be profound since only a few antiprotons are expected to be created in collisions of cosmic rays with interstellar (or intergalactic) matter and creation of more complex antinuclei through collisions is negligible. Thus the observation

of even one antihelium nucleus in the cosmic ray flux would almost certainly prove the existence of antimatter stars, or at the least, accumulations of antimatter somewhere in the universe.

Alfven[1] has suggested that the galaxy (and universe) is divided up into cells of matter and antimatter; these cells are prevented from interacting (and annihilating) by the creation of a high-energy plasma leiden frost between them. However, if the energy of a particle is high enough, it can pass through the barrier. Alfven has suggested that this occurs for particles above 10^8 MeV, although some leakage is possible at lower energies.

Should whole galaxies be composed of antimatter, a measured flux of antinuclei would give a direct measure of the leakage spectrum of cosmic rays from the galaxies. A measured spectrum shape and intensity could well lead to the elimination of one of the theories of the seat of antimatter.

Two types of measurements have been made that have placed limits on the intensity of incident antinuclei in the primary cosmic ray flux. First, direct measurements of the flux of primaries have placed upper limits of from 10^{-2} to 10^{-3} for the related intensity of antinucleons. In addition, indirect measurements are possible based on gamma ray flux measurements. The limits obtained are based on the known annihilation of nucleons producing π° mesons, which in turn decay to two gamma rays. Cline[2] and Kraushaar[3], based on their data, were able to place an upper limit of 10^{-8} to 10^{-9} for the admixture of antimatter in the cosmic radiation.

One of the sources of antimatter in cosmic rays is secondary production in interstellar matter. Calculations[4, 5] have shown this to be 10^{-4} to 10^{-6} for antiproton production and $\sim 10^{-10}$ for antihelium production. Thus measurements with the capability of $\sim 10^7$ events should show antiprotons even if none are present in the primary radiation. If antihelium nuclei are present to about 10 percent, as are alph particles in normal cosmic rays, then measurements of 10^7 to 10^8 events should be capable of distinguishing between the presence of primary and secondary antimatter in cosmic rays.

3. Description of Research

The primary instrument in the experimental setup for this cluster is the superconducting magnet. No other instrument that would be practical for the space station has the ability to determine the sign of the charge of a high energy nucleus. This it does by bending antinuclei in the opposite direction from that of the normal nuclei.

In addition to the usual problem of determining the trajectory of the particle before and after passing through the magnetic field,

the directional sense of the particle must be determined, whether the particle is passing from left to right or from right to left. Both of these problems can be solved by the use of an appropriate array of scintillation counters and spark chambers. The scintillation counters provide a trigger for the spark chambers that are placed on each side of the magnet. (The tracks through the spark chambers determine the trajectory of the particle before and after being bent by the magnet.) At the same time, moreover, the scintillation counters' pulses will provide a time-of-flight analysis of the particle which triggered them, i.e., the pulse timing sequence will determine the directionability of the particle passing through the system. This is particularly important since a major background would likely be an albedo flux of alpha particles that would travel through the superconducting magnet in the wrong direction and be bent in the direction of antiparticles passing through in the correct direction.

In addition to this array of scintillators and spark chambers for use with the superconducting magnetic, a measurement of the total energy of the incident antiparticle is required if an unambiguous determination of particle identity is to be made. Such a measurement could be provided by the TANC (total absorption nuclear cascade) counter. A description of this counter is provided in the facility equipment description, and in 4-CR-1, in which it was suggested as a possible detector.

4. Impact on the Spacecraft

No additional equipment is required for this experiment cluster over what should be provided for the spacecraft cosmic ray laboratory as a whole. Again, only a slight reconfiguring of the experiment technique for 4-CR-1 for measuring the charge and energy spectrum of incoming cosmic rays would be required. Indeed these experiments could both be run concurrently. Only the addition of the time-of-flight analysis system would be required for this cluster.

Again, the initial setup and checkout would be done by the astronaut, with the aid of an onboard computer for automatic setting and testing of the logic sequence and signal trigger levels. For example, this experiment would be set to be triggered by alpha particles for one investigation, and by protons for another.

The experiment data from the various counters would be digitized and placed in computer storage for later transmission. Once the experiment had been set up, aligned, and calibrated, it should be run continuously, with automatic periodic testing and calibration until sufficient data had been collected to provide for adequate statistical analysis of the results.

5. Required Supporting Technology Development

Except for the development of the superconducting magnet system and of total absorption counters, as described in 4-CR-1, no

additional development work is required. There are, of course, details in timing sequences and detector geometry to be worked out, but the problems are well understood and the solutions will be derived as a part of the detailed experiment configuration description.

6. References

1. H. Alfven. Worlds-Antiworlds, Antimatter in Cosmology, W.H. Freeman and Co., San Francisco, 1966; Alfven, H., Rev. Mod. Phys. 37, 652 (1965).

2. T.L. Cline. Phys. Rev. Lett's. 7, 109 (1961).

3. W. Kraushaar, G.W. Clark, G. Garmire, H. Helmken, P. Higbie, and M. Agagino, Ap. J. 141, 845 (1965).

4. S. Hayakawa, K. Ito, and Y. Tereshima. Origin of Cosmic Rays, Prog. of Theoret. Phys. Suppl. 6, 1 (1958).

5. S. Rosen. Phys. Rev. 158, 1227 (1967).

Critical Issues Addressed by Research Cluster

4-CR-5
ANTINUCLEI IN COSMIC RAYS

4.2.1.3.3.2.2.1.3.1
Are any anti-protons or anti-nuclei present in the primary cosmic rays?

RESEARCH CLUSTER SYNOPSIS—SPACE PHYSICS 4-CR-6 Quarks (Stable Fractionally Charged Particles) in Cosmic Rays

1. Research Objectives

Many of the unsolved problems and experimental measurements of high-energy particle physics have been explained through the mathematical construction of three particles with fractional charge. Many searches have been made for these particles over the last 10 years or so. Their discovery in a space laboratory as part of the incident cosmic-ray beam would be of immense interest to the scientific community and would thus provide a very firm foundation for the utility of a cosmic-ray facility on the spacecraft.

In addition to their use in searching the incident radiation for these particles, the high-energy particles in the incident flux could also be used as a beam to produce these particles since no predictions exist for the mass (and hence production threshold) of these particles. Two questions can therefore be answered by this cluster: (1) Do quarks exist in the cosmic rays or can they be produced by cosmic rays? (2) if they do exist, what is the threshold for their production, i.e., their mass?

2. Background and Current Status

Quarks were mathematically discovered by Murray Gell-Mann[1] and Georg Zweig[2], working independently in 1964, which helps explain the basis for the success of the mathematical symmetries used to treat the strongly interacting particles. In particular, the basic components in this theory of elementary particles are characterized by a triplet of the nuclear quantums of spin, strangeness, and fractional change. These components are used to generate members of the families particles in these symmetry systems. The fractional charges are either 1/3 or 2/3.

The quark model has had great success theoretically for several reasons. It did correctly predict the existence of the Ω^-particle and its usefulness as a guide to the classification of states of elementary particles has been firmly established.[3] Another particle whose reality has been a mystery for the past decade is the scalar meson, a particle needed for certain nuclear potential models. The quark model leads to the viewing of mesons as tightly bound states of quarks and antiquarks, with different mesons being excited states of the system. The existence of quarks leads to the prediction of the existence of the scalar meson.

Recent calculations using the quark model have been successful in obtaining values for the proton and neutron magnetic moments

in obtaining meson and baryon reaction rates, and in establishing order in the list of over 300 baryons and close to 100 mesons that have been experimentally discovered. Indeed, this model, with its inherent simplicity, may be the key to our understanding of the realm of high-energy particle physics, a key for which theorists have been searching for more than 20 years. Although quarks themselves have been considered by theorists as only a mathematical device, others have taken the model to be a prediction of the existence of these particles, and numerous schemes have been devised for detecting them.

Accelerator searches at CERN, in the Soviet Union, and at Brookhaven, among others, have been made. For quarks with masses below 5 GeV, an upper limit to their cross section for production is 10^{-36} to 10^{-39} cm^2; i.e., essentially no quarks exist with energy less than 5 GeV. Upper limits to the intensity of quarks in cosmic rays have been set by groups working at CERN, Universities in Tokyo and Arizona, and at other locations throughout the world. Flux limits on the order of 1×10^{-10} particles cm^{-2} $ster^{-1}$ sec^{-1} have been placed on each of the three types of quarks. These cosmic-ray experiments were all performed on the Earth's surface, however, and atmospheric effects could have affected the results. Geophysical searches for quarks have also been made in various samples of terrestrial and meteoritic materials, including lava, sea water, and oil, again without success. Upper limits in terrestrial material as low as 1 quark per 10^{26} nucleons, and in meteorites of 1 quark in 10^{17} nucleons, have been placed.

Two experiments have been reported, in which quarks have been observed, but there is much controversy over the discovery. McCusker, et al, have reported seeing tracks in Wilson cloud chambers that can only be explained by assuming the existence of a fractionally charged particle.[4] Chu, Kim, Beam, and Kwak have presented evidence that they believe indicates a charge 2/3 particle passed through the Argonne-Michigan heavy-liquid bubble chamber.[5] Both of these claims are currently being disputed on the basis of the statistics of track density and track frequency.[6] At present the controversy continues, making it doubtful that the results of either of these experiments will ever be considered a definitive discovery of the quark unless further supportive work is performed. The intense interest in these experiments makes the search for quarks an excellent objective of the cosmic-ray laboratory in the spacecraft.

3. Description of Research

The experiment to discover quarks is primarily one of identifying a fractionally charged particle. This parameter, therefore, should be overconstrained to aid in positive identification. Also of fundamental interest is the mass of the particle, with secondary interest in its energy.

The experiment itself could be instrumented, using detectors and electronic counters, rather than by using a bubble chamber. The identification of fractionally charged particles must be positive (i. e., with minimum statistical fluctuations) and will necessarily be performed in the presence of a large charge 1 background. One technique could involve the use of spark chambers (triggered by scintillators), the superconducting magnet for bending the particles, and energy-loss and total-energy detectors. The energy-loss detectors will be particularly useful because the ionization rate for minimum ionizing charge 1/3 quarks is only 0.11 (that of singly charged particles) and for charge 2/3 quarks it is 0.44. The spark chambers will define the particle track into, and out of, the magnet, which, in conjunction with the measurement of energy through the total energy detector, will give a measure of energy, charge, and mass.

For such a counter experiment, the detectors and magnet would be set up, aligned, and calibrated. Electronic thresholds would be set for the detector electronics and coincidence circuitry, possibly through the use of an onboard computer. The computer-set logic could determine the properties of the particles passing through the detectors and then pick out those that meet the requirement of fractional charge. Because of the importance of a single discovery, all of the levels in all the detector electronics should be stored for later transmission, and a special calibration sequence should be performed immediately following the event to be certain that all equipment is functioning properly.

4. Impact on Spacecraft

The equipment used for this experiment will be essentially the same as that described in previous research clusters, particularly 4-CR-1. Again, the astronaut-scientist will be required to set up the experiment, align the various detectors and magnet, and perform an initial calibration. A computer calibration will also be used as a check on the system as well as the computer connections.

Weight and power requirements are similar to those for 4-CR-1, with telemetry requirements being minimum. It is, in fact, quite possible that this experiment could be combined with 4-CR-1, with a special computer flag being set when and if a fractionally charged particle is detected.

5. Required Supporting Technology Development

There are no special requirements for this cluster since the detectors are all part of previously described clusters.

6. References

1. M. Gell-Mann. Phys. Letters 8, 1964, p. 214.

2. G. Zweig. CERN Report TH 401, January 1964. TH 412, February 1964.

3. N. Barash-Schmidt, A. Barbaro-Galtieri, L.R. Price, A.H. Rosenfeld, P. Soding, C.G. Wohl. M. Roos, and G. Conforto. Review of Modern Physics, Vol. 41, 1969, p. 109.

4. C.B.A. McCusker and I. Cairns. Physical Review Letters, Vol. 23, 1969, p. 658. I. Cairns, C.B.A. McCusker, L.S. Peak, and R.L.S. Woolcott, Physical Review, Vol. 186, 1969, p. 1394.

5. W.T. Chu, Y.S. Kim, W.J. Beam, and N. Kwak. Physical Review Letters, Vol. 24, 1970, p. 917.

6. W.W.M. Allison, M. Derrick, G.P. Hunt, J.D. Simpson, and L. Voyvodic. Physical Review Letters, Vol. 25, 1970, p. 550.

7. Bibliography

Frauenfelder, H., V.E. Kruse, and R.D. Sard, Phys. Rev. Letters 24, 33 (1970).

Adair, R.K. and H. Kasha, Phys. Rev. Letters 23, 1355 (1969).

Critical Issues Addressed by Research Cluster

4-CR-6
QUARKS (STABLE FRACTIONALLY CHARGED PARTICLES) IN COSMIC RAYS

4.2.1.3.3.2.2.1.3.4
Are there any stable fractionally charged particles present in the primary cosmic radiation (quarks)?

RESEARCH CLUSTER SYNOPSIS—SPACE PHYSICS
4-CR-7
Unknown Particles in Cosmic Rays

1. Research Objectives

Experiments in this research group, by their very nature, are difficult to define because the properties of the particles that might be found are unknown. In this area, most of the searching is for particles that cannot be produced in an Earth-bound laboratory for either or both of two reason: (1) the interaction energies necessary to produce these particles may have to be much greater than are attainable with accelerators, or (2) the cross sections for production may be so small that only the long time scales associated with the age of the galaxy or the solar system may give the total integrated flux required to yield a reasonable probability of production. Events that fall into the latter category can sometimes be traced by studying recovered meteorites or, more recently, lunar rock samples.

In addition to a search for new or unknown particles in the incident radiation, there are theoretically postulated particles for which more specific experiments can be devised. In either case, the objective here is to analyze the incoming cosmic-ray beam before it interacts with the atmosphere to discover rare particles that have not been detected on the Earth, thereby proving the value of a laboratory in space. Of course, the discovery of a new particle has often, in the past, led to rapid developments in the theory of nuclear and particle structure, and such a discovery here could well have a similar stimulating effect.

2. Background and Current Status

As pointed out above, it is not possible to project the effect that experiments searching for unknown particles will have on cosmic-ray and high-energy particle physics, or on the space program. Possibly only negative experiments will be performed; i. e., new lower limits will be placed on cross sections or abundancies. However, the rewards for discovering a new particle are so great in terms of the theoretical advances that could be attained that the experiment is well worth performing. This is especially true because such experiments, for the most part, are simply the identification of unusual events in other experiments. An exception to this occurs, however, when a specific particle is being searched for. An example of this is the search for magnetic monopoles.

Dirac has theorized that electric charge quantization can be explained on the basis of the existence of magnetic monopoles; i. e., particles that interact with magnetic fields in the same way that electric charges interact with electric fields, serving as a source for the field and being accelerated by it.[1] Dirac further

predicted that such particles would be stable, and that the ratio of magnetic charge g to electric charge e would be

$$g/e = n\frac{\hbar c}{e^2}$$

where n is an integer. Swinger has gone on to elaborate on Dirac's idea by postulating that a single particle, carrying both electric and magnetic charge, would be a fundamental building block in the subnuclear world.[2] Forces between magnetic charges would be superstrong since the coupling constant, $g_o^2/\hbar c$, is on the order of 4 (137), in comparison with nuclear forces for which coupling constants are on the order of 10. The existence of Schwinger's dyons would not only explain the universal quantization of electric charge, but would completely symmetrize Maxwells' equations between electric and magnetic charge, give meaning to the subnuclear properties of isotopic spin and of hypercharge, and explain the weak violations recently found of CP symmetry (where C represents charge and P represents parity). The discovery of dyons, therefore, would indeed be of fundamental physical importance.

Several searches have been made for magnetic monopoles, all unsuccessful so far. Alvarez, et al, have search 8.37 kilograms of lunar surface material for monopoles that either belonged to the primary cosmic rays or were produced in the collision of a high-energy cosmic-ray particle with a nucleon of the lunar surface.[3] The attractiveness of the lunar surface involves its great age (3 to 4 x 10^9 years) and the small depth to which the surface has been churned. No monopoles were found, although a single one on minimum predicted strength in the sample would have produced a signal 8 times the standard deviation error of the experiment. Other unsuccessful searches have been made in the earth's atmosphere,[4] in surface rocks,[5] in deep ocean deposits,[6] and in meteorites.[7] There have also been unsuccessful accelerator searches for these particles, the most extensive of which was performed at CERN, using a 28-GeV proton beam.[8] Because of the theoretical significance of finding magnetic monopoles, we can expect additional searches for them to be undertaken.

3. Description of Research

Again, since we do not know what to expect, specific experiments cannot be set up. By analyzing the data from other experiments in the laboratory, new particles may be detected. In the future, other theoretical predictions may indicate that a particular experimental program should be undertaken in a search for some particular particle. If such a need arises, the Space Station laboratory will be capable of providing the counters and detectors necessary, since this laboratory is, indeed, being designed as a complete as possible high-energy physics and cosmic-ray laboratory.

To carry the particular example of searching for magnetic monopoles further, the detection arrangement for detecting heavy

cosmic-ray primaries could be used here since these particles at high energy are expected to ionize at 4700 times the minimum ionization produced by a singly charged particle. Should such tracks be found in the exposed emulsions or plastic detectors, a search using magnetic fields could be performed on the ground to isolate the particles in these detectors. The upper limit for the intensity of such particles has been placed in the range from 10^{-13} to 10^{-19} particle cm^{-2} sec^{-1} sr^{-1}, depending on the assumptions made in the data analysis. For the maximum flux, a detector area of 3 square meters would show only one monopole track per year, a not very hopeful situation. However, assumptions (some of which may be questionable) have been made in the experimental analysis, so that the experiment is not without hope. Furthermore, the cross section for monopole production may get very large at high energy so that the incident very-high-energy cosmic-ray flux may lead to the production of these particles. The important point is that these monopoles are stable and the discovery of just one of them would provide all the statistically significant data required for the experiment.

4. Impact on Spacecraft
This particular research area will provide no real impact on the spacecraft in itself, since the experimentation in this area will be part of the other experiments being performed.

5. Required Supporting Technology Development
No supporting research or technology development is required.

6. References

1. P.A.M. Dirac. Proceedings of the Royal Society. Ser. A133, 1931 p. 60. Physical Review, Vol. 74, 1948, p. 817.

2. J. Schwinger. Physical Review, Vol. 173, 1968 p. 1536. Science, Vol. 165, 1969, p. 757.

3. L.W. Alvarez, P. Eberhard, R. Ross, and R. Watt. Science, Vol. 167, 1970, p. 703.

4. W.C. Carithers, R. Stefanski, and R.K. Adair. Physical Review, Vol. 149, 1966, p. 1070.

5. L.W. Alvarez, A.J. Schwemin, R.G. Smits, and R.D. Watt. Semiannual Report, UCRL 11466, October 1964, p. 6 (unpublished).

6. R.L. Fleischer, H.R. Hart, I.S. Jacobs, P.B. Price, W.M. Schwartz, and F. Aumento. Physical Review, Vol. 184, 1393, 1969, p. 1393.

7. V.A. Petukhov and M.N. Yakimenko. Nuclear Physics, Vol. 49, 1963, p. 87.

8. E. Amaldi, G. Baroni, A. Manfredini, H. Bradner, L. Hoffman, and G. Vander Haeghe. Nuovo Cimento, Vol. 28, 1963, p. 773.

Critical Issues Addressed by Research Cluster

4-CR-7
UNKNOWN PARTICLES IN COSMIC RAYS

4.2.1.3.3.2.2.1.3.5
Are there any particles in the cosmic rays with properties yet unknown?

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

SPACE PHYSICS

RESEARCH CLUSTER—4-CR-8
CHARACTERISTICS OF ALBEDO PARTICLES ABOVE 100 MeV

RESEARCH CLUSTER SYNOPSIS—SPACE PHYSICS
4-CR-8
Characteristics of Albedo Particles above 100 MeV

1. Research Objectives

The characteristics of the cosmic ray albedo are not well known at the present time. Its existence, however, is of interest for several reasons. First, it provides a background for other experiments in the cosmic ray physics laboratory; second, a measure of the intensities and energy spectra of all components of the albedo will provide important data toward increasing understanding of the interaction of high-energy cosmic rays with the atmosphere; and third, this albedo is a property of the near-Earth space environment itself, and as such could affect many of the processes taking place there. For example, the inner radiation zone is believed largely populated by protons from the decay of albedo neutrons.

2. Background and Current Status

The cosmic ray albedo is the flux of particles leaving the atmosphere as a result of bombardment by cosmic ray primaries. The great majority are secondaries generated by interactions of the primaries in the atmosphere; the contribution from back-scattered primaries can be neglected.

The interactions of primary cosmic rays have been studied extensively, principally with balloon-borne nuclear emulsion stacks. A review of this work has been published by Camerini, et al[1]. When a high-energy particle collides with a nucleus in the emulsion, it generates a cosmic-ray star. A typical star has light tracks collimated in the direction of the primary, and heavy tracks of particles which are emitted isotropically. The interpretation is that the light tracks are made by particles (protons, mesons, etc.) generated in the collision. As a result of the collision, the nucleus is left in an excited state, and boils off nucleons which typically have an energy of 10 MeV.

Because of the strong collimation in the forward direction, only a small fraction of the high-energy particles will leave the top of the atmosphere. This problem has been treated by Hess[2] who calculated the number of neutrons emitted from the atmosphere (see his figure 7). Approximately the same number of protons is generated, but, for charged particles, account must be taken of the energy loss by ionization, and deflection by the Earth's magnetic field after leaving the atmosphere.

In the energy range 100 MeV to 1 GeV, it is estimated the flux of secondary protons leaving the top of the atmosphere to be of the order of 10^{-6} cm^{-2} sec^{-1} MeV^{1} at the equator, and an order of magnitude higher at the poles.

In a field of 0.5 gauss, the radius of curvature of a 100-MeV proton is $\rho = 30$ km. For $\rho = 500$ km, the energy is 6.7 GeV. If, for example, the spacecraft is at an altitude of 500 km above the equator, protons below 3 GeV cannot reach it directly, but must leave the atmosphere at about 15 degree (N or S) latitude and spiral up the line of force. The flux will vary with geocentric distance approximately as $1/r^6$.

The measurement of the flux and energy distribution of neutrons leaving the atmosphere is important because of its bearing on the population of the radiation belts[3]. This measurement has been made[4] and the results agree within a factor of 2 with the calculated fluxes.

The flux of high-energy positrons and electrons leaving the atmosphere constitutes an important background for the measurement of the electron-positron component of the primary cosmic rays. The importance of this measurement is discussed in 4-CR-2.

The flux and energy spectrum resulting from the decay of π° and $\pi^\pm$ mesons in the atmosphere have been calculated, and measurements are available below 10 GeV[5]. In this energy range, these measurements agree with the calculations within the (rather large) statistical error.

3. Description of Research

A sample experiment for this cluster would be the determination of the spectrum and intensity of albedo electrons and positrons above 100 MeV, and how they change with geomagnetic coordinates and with time. For this experiment, the magnet would be used to distinguish the electrons from the positrons, and also to measure their momentum. The trajectory through the magnet would be determined by two-dimensional spark chambers at the entrance and exit of the magnet. These in turn would be triggered by scintillation counters. To distinguish these particles from the nuclear component of the albedo, a measurement of energy is required. A total absorption scintillation counter (TASC) could be used for this purpose. The passage of a high energy electron or positron through the TASC would lead to the creation of an electromagnetic shower or cascade. This would further distringuish these particles from protons, which cause nuclear cascades. To distinguish between primary particles and albedo particles, a time of flight system could be used by time analyzing the scintillation pulses. This last step is not strictly necessary since the directionality is also determined by the development of the electromagnetic shower in the TASC. However, the timing of pulses requires only a modest amount of electronics and in any case, is required for other experiments (e.g., the search for antinuclei) in the laboratory, while the overall redundancy will provide additional support for the experimental results. While measurements are being made, the direction of the

spacecraft with respect to the Earth and the local magnetic field must be known.

4. Impact on Spacecraft

For the most part, the experimental setup and data collection for this investigation will be a part of the other experiments on the space station. Indeed, the albedo itself provides an important source of background so that, in effect, all experiments will indirectly provide data for this cluster. This is especially true in regards to measurement of the temporal and spatial distribution of the albedo. Thus, there is no direct impact on the spacecraft for this cluster, the results for which will be derived from analysis of data from other experiments.

5. Required Supporting Technology Development

Since no special experimental facilities are required for this cluster, no supporting research and technology is necessary.

6. References

1. Camerini, Lock and Perkins: Progress in Cosmic Ray Physics, Vol. I (1957).

2. Hess, Canfield and Lingenfelter, J. of Geophysical Research, 66, 665 (1961).

3. W.N. Hess, The Radiation Belt and Magnetosphere; Blaisdell, 1968.

4. Hess and Starnes, Phys. Rev. Letters 5, 48 (1960).

5. Daniel and Stephens, Phys. Rev. Letters 15, 769 (1965).

Critical Issues Addressed by Research Cluster

4-CR-8
CHARACTERISTICS OF ALBEDO PARTICLES
ABOVE 100 MeV

4.2.1.3.3.2.2.3.5
What are the characteristics of the albedo particles above 100 MeV?

RESEARCH CLUSTER SYNOPSIS SPACE PHYSICS
4-CR-9
Nucleon-Nucleon Cross-Sections at High Energies

1. Research Objectives

The experiments for this research cluster are directed towards measuring the cross sections of the p-p, p-n and n-n interactions at high energies. These measurements include the detection and analysis of any new, as yet undiscovered, particles that may be produced in the interactions. To perform these measurements, cosmic-ray primaries of energies greater than any attainable in a present-day laboratory would be used as the particle beam. The These measurements, then, would utilize one of the unique characteristics of the space environment for carrying on experiments not feasible on Earth, a major goal of a spacecraft laboratory.

The goals of this research cluster include measurements of (1) 1-1 total gross-sections at high energies to determine the asymptotic behavior with energy, (2) p-p differential cross-sections at high energies to determine the behavior of the forward diffraction peaks as a function of energy, (3) study of the transverse momenta distributions from high-energy interactions, and (4) correlation of transverse and longitudinal momentum, multiplicities and total energy to test multiperipheral theories, or more generally, to determine whether the strong interaction becomes quantitatively different at very high energies?

2. Background and Current Status

Many of the questions in interaction physics that cannot be answered with the energies currently available at high-energy accelerators would benefit greatly from a spacecraft facility. Several predictions of the Regge pole model require higher energies for adequate testing. For example, the usual Regge pole model predicts that as the energy goes to infinity the total cross-sections tend toward constants and that particle and antiparticle cross-sections on the same target tend toward equality (Pomeranchuk theorem). It is unnecessary to work with the highest possible energy to verify these predictions but with energy only a few orders of magnitude greater than the levels now possible at accelerators.

There is a strong indication that as the center of mass energy of a collision becomes much larger than the sum of the rest masses of the secondaries, the spectrum of these particles should assume a simple and universal form when such a spectrum is expressed in terms of the appropriately chosen variables. This simple dependence has not been found at accelerator energies and may require much higher (cosmic-ray) energies.

In elastic scattering, Regge theory also predicts that a reaction in which a single pole is dominant should exhibit a narrowing

(shrinkage) of the forward peak as the energy increases. Such shrinkage has not been observed up to 30 GeV. Again, accessibility to higher energies is needed to try to observe these predicted effects.

We also include, in this broad area of differential cross-sections at high energies, the production cross-sections for quarks and magnetic monopoles.

Three fundamental nuclear reactions can be studied, using the incoming cosmic-ray beam as the energetic particle source: (1) the p + p interaction by bombarding a hydrogen target with the incident proton beam, (2) the p+n interaction by using a denterium target and the proton beam (and subtracting out the already determined p+p cross section), and (3) the n+n reaction by using the denterium target with the primary alpha particles as the beam (and subtracting out the p+p and p+n cross sections). Again, each of these reactions would be used to measure total and differential cross sections, as well as the angular and energy distribution of the secondaries.

3. Description of Research

To make effective use of the cosmic-ray laboratory in studying high-energy interactions, the incident beam should be of higher energy than that obtainable in an Earthbound laboratory. It is therefore important to study the beam capabilities of both current and planned accelerators.

The highest energy currently available is from Serpukov machine at 70 GeV. The CERN intersecting storage rings are scheduled to be available in the summer of 1971, with a center-of-mass enregy of 50 GeV (which corresponds roughly to an incident energy of 10^{12} eV). The National Accelerator Laboratory (NAL) synchrotron at Batavia, Illinois, will be capable of operating at 500 GeV, with experiments likely to begin in 1972. It has also been proposed to add intersecting storage rings at NAS, although such a development is well in the future. This latter proposal would give an equivalent beam energy of about 10^{14} eV. From this discussion, then; we can expect the cosmic-ray laboratory to be useful only for studying reactions above about 10^{12} eV, with possible later developments raising this value to 10^{14} eV. For a reasonable geometry, i.e., detector areas of a few square meters and path lengths within the system of about 10 meters, counting rates of approximately 10^3/day above 10^{12} eV or 1/day above 10^{14} eV can be expected.

A possible experimental setup can be thought of as consisting of four parts, an incoming particle identification system, a hydrogen target, a magnetic spectrometer, and a total-energy detector.

The incoming-particle identification counter system could consist of a Cerenkov counter and a scintillator for charge determination, and a spark chamber for directionality information. The target would be liquid (or solid) hydrogen or deuterium, because the presence of more-complex nuclei would make the results very difficult to interpret and a gaseous target would be of insufficient density to obtain a significant number of interactions. The magnetic spectrometer will be used to analyze the reaction products to be studied; for example, the transverse momenta distribution from the high-energy interactions. To use the spectrometer effectively, detectors of higher spatial resolution (microns) must be developed. At present, spark chambers are capable of achieving resolutions of approximately 0.1 mm, and it is doubtful that this figure can be significantly improved. Emulsions have the necessary resolution for analysis of secondaries up to 10^{14} e 10^{14} eV, but finding a method for sorting out of the multitude of tracks presents an unsolved problem. Liquid proportional count counters are currently under development, and they may offer a solution. A total energy detector to determine the energy of the reaction products (from which the energy of the incident particle is deduced) could be a total-absorption nuclear cascade (TANC) counter. Scintillators, both in-coincidence and anticoincidence, and time-of-flight analysis would be used to reduce the background, trigger the counting system, and roughly define the particle trajectories.

4. Impact on Spacecraft

Most of the instruments in this cluster and their impact on the space station have already been discussed elsewhere.

In addition to this equipment, a liquid-hydrogen target is required, specifically for the high-energy interaction experiments. This target will be about 2 m thick and 1 to 2 m on a side, the exact size being determined by the final design of the laboratory. The use of liquid hydrogen presents a safety problem, both in terms of appropriate valving to keep the pressure low and in the fire and explosion hazard.

The equipment required in this cluster is probably the most extensive of any in the space laboratory. Except for the liquid-hydrogen target, however, all of the necessary equipment and detectors would be an integral part of the laboratory, whether or not interaction physics experiments were performed. The experimental arrangement therefore consists of setting up the detectors, target, and magnetic spectrometer, and their associated electronics with the appropriate geometry. The initial setup and checkout would be performed by the astronaut with the aid of an onboard computer for automatic setting and testing of the logic sequence and signal trigger levels.

The experiment data from the various counters would be digitized and placed in computer storage for later transmission. The film record from the streamer chamber would be numbered and dated for correlation with the stored data. The film could be stored and returned to earth for development and scanning, or if possible, developed on the station to keep fogging and background at a minimum and to eliminate the necessity for postexposure shielding.

Once the experiment has been set up, aligned, and calibrated, it could be run continuously with automatic periodic testing and calibration until sufficient data were collected to allow adequate statistical analysis of the results.

5. Required Supporting Technology Development

The use of a hydrogen target is the only unique instrumentation technique required by this cluster. For maximum density, the target must be liquid or, if possible, solid. Therefore, a cryogenic system is required that can operate at liquid-hydrogen (or lower) temperatures. This system must be capable of controlling several cubic meters of liquid or solid hydrogen, and must not be a hazard to the astronauts. The development of such a system could well be part of the development of the liquid-helium system for the super-conducting magnet.

The details of detector geometry timing sequences and film advancing and coordination must be worked out, but the problems are well understood so that solutions will be derived as part of a detailed experiment configuration description.

Critical Issues Addressed by Research Cluster

4-CR-9
NUCLEON-NUCLEON CROSS-SECTIONS AT HIGH ENERGIES

4.1.5.3.6.1.1
What are the total p-p, p-n, and n-n cross-sections at high energies?

4.1.5.3.6.1.2
What are the differential p-p, p-n, and n-n cross-sections at high energies?

4.1.5.3.6.1.3
What are the angular and energy distributions of secondaries produced as a function of incoming proton and alpha-particle energies?

RESEARCH CLUSTER SYNOPSIS—SPACE PHYSICS
4-CR-10
Spallation Cross Sections at High Energies

1. Research Objectives

The study of nuclear spallations involves measuring the reaction rates and reaction products from high-energy nuclei on protons. The particles in the primary cosmic radiation will serve as the beam for these measurements. Thus, the experiments in this cluster will utilize the same space environment characteristic that was used in Research Cluster Differential Nucleon-Nucleon Cross Sections at High Energies. Here, we are again making use of a unique property of the space environment that is not attainable on the surface of the Earth; viz., the presence of particles of higher energy than can be produced by today's accelerators. There is, however, an essential difference between the future possibilities for surface-based experiments in this area and in the nuclear reactions area.

As pointed out in Research Cluster 4-CR-9, higher-energy machines are being built that will ultimately attain an equivalent beam energy of 10^{14} eV. However, these energies are attained through the use of a colliding-beam technique; that is, two beams of much lower laboratory energy will interact. Since only proton beams w ll be used, the energy of a single beam, 5×10^{11}eV, at the National Accelerator Laboratory (NAL), represents the highest energy at which spallation reactions can be studied. Even at this energy, spallation experiments will be difficult because of the problem of determining the charge of the product nucleus. The experiment should be performed with nuclei incident on protons. For the value $Z \geq 6$, the energies available from accelerators are limited to less than 100 MeV per nucleon.

A laboratory in space can be expected to remain the best place for performing these experiments for many years.

In addition to their intrinsic interest, data on spallation cross sections as a function of energy are important because of their bearing on the passage of cosmic-ray primaries through interstellar space. In the galactic disc, this space is filled with hydrogen gas with a density of about 1 atom/cm^3. As the various nuclei that make up the primary cosmic radiation pass through this gas, they suffer collisions which result in spallation, and hence in a change in composition of the beam. Certain elements (e.g., Li, Be, B, and F) have a much higher relative abundance in the cosmic radiation than found in the lithosphere or meteoroids. If we assume that these excess nuclei result from spallation, and we know the spallation cross sections as a function of energy, we can deduce the number of grams per cm^2 of interstellar gas that the primaries have passed through. This, in

turn, can be related to the mean lifetime of the primaries, if they are assumed to stay in the galactic disc; or if the lifetime is measured in some other way (e.g., by the Be^{10} energy spectrum), we can deduce the fraction of the time that the particles stay in the disc.

2. Background and Current Status

Measurements of spallation cross sections have been reported by Cleghorn et al.[1] These measurements involved cosmic-ray nuclei with the value $Z > 10$, and the measurements were made in nuclear emulsions flown near the top of the atmosphere. Spallation data are necessary for the interpretation of the results of balloon experiments, because a correction is necessary for interactions in the residual atmosphere above the equipment. The atomic numbers of nuclei were measured both by delta-ray count and by track density, with an error of 1 or 2 charge units.

Nuclei were divided into four groups: VH ($Z > 20$), LH ($10 \le Z \le 19$), M ($6 \le Z \le 9$), and L ($3 \le 7 \le 5$). The fragmentation parameters $P_{VH,VH}$; $P_{VH,LH}$; $P_{VH,M}$; and $P_{VH,0}$ in emulsion were obtained for the following energy intervals (expressed in MeV/nucleon): 0 to 400, 400 to 800, and greater than 800. $P_{VH,0}$ refers to interactions in which no fragments with $Z \ge 3$ were produced.

Spallation cross sections at lower energies have been extensively studied with accelerators. We shall be concerned here, however, with energies present in the (high-energy) primary cosmic radiation.

To elucidate the history of the cosmic-ray primaries, it will be necessary to get data for the interaction of nuclei with hydrogen; to determine $P_{x,y}$ in much greater detail; and to measure the variations with energy to higher energies.

3. Description of Research

The purpose of the investigation is to determine the probability $P_{x,y}$ that a nucleus of charge x, interacting with a hydrogen atom, will produce a nucleus of charge y. We do not propose to do this with a proton beam incident on a target of atomic number x, because of the difficulty of measuring y in that case. The experiment will therefore involve nuclei of charge x incident on a hydrogen target.

In a typical experiment, we envision a particle passing in turn through a transition detector and a multiwire proportional counter, which between them determine the charge, energy, and location; a chamber containing liquid or solid hydrogen, about 10 cm thick and with front and back windows of minimum thickness; a superconducting magnet to separate low-energy particles (e.g., $\pi^{\pm}$ - mesons) from the primary; and a second multiwire

proportional counter to determine the final energy. Other counters may be added to better define the particle trajectories and energies, and the energy of the incoming particle may be determined by deflection in the magnet or the use of the total-energy spectrometer. If the latter is not used, the experiment can probably be run at the same time as other experiments. If will be important to minimize the amount of material (other than hydrogen) in the path of the particle, since the heavy primaries have mean free paths for nuclear interactions of a few g/cm^2.

4. Impact on Spacecraft
If we assume that the spacecraft already contains a large superconducting magnet and the associated cryogenic facilities, the only requirement on the spacecraft is that there be sufficient room around the magnet to accommodate this experiment in addition to the others contemplated. Power requirements for the counters will be modest. Some increase in the capacity of the cryogenic system may be required to take care of the liquid (or solid) hydrogen, and the data rates will be comparable to those for the other counting experiments.

5. Required Supporting Technology Development
This experiment, in common with others, would benefit greatly from the development of a transition detector capable of measuring γ, the ratio of total energy to rest energy. In the absence of such a detector, the use of the total-energy spectrometer will be required. Such detectors are under development.

A multiwire proportional counter with good spatial resolution is also required. Any improvement in the present resolution would be an advantage, since it would facilitate the separation of the particles after the interaction.

6. References

1. Cleghorn, Freier and Waddington, Contribution OG-VV-54 to the Tenth Cosmic-Ray Conference, Calgary.

Critical Issues Addressed by Research Cluster

4-CR-10
SPALLATION CROSS-SECTIONS AT HIGH ENERGIES

4.1.5.3.6.2.1
What are the spallation cross-sections of heavy nuclei on hydrogen?

4.1.5.3.6.2.2
What is the multiplicity of charged-particle production from nuclear-spallation reactions?

4.1.5.3.6.2.3
What is the energy distribution of the outgoing particles from nuclear-spallation reaction?

4.1.5.3.6.2.4
What is the angular distribution of the outgoing particles from nuclear-spallation reactions?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER
NO. 4-CR-1 thru 10

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
4-CR-1 thru 10												
-1	Set-up experiment equipment (Mechanical positioning, electronic control)	Listed Below	3	None		7A/5B/5B	1	4800/EXPMT	3	OPERATES CONTINUOUSLY FOR EXPERIMENT PERIOD ≈6 MONTHS		
-2	Calibrate Instruments		4	"		"	1		3			
-3	Maintain Equipment		4	"		"	As Req.		3			
-4	Initiate Experiment		5	"		"	1		3			
-5	Monitor & Log Operational Data	Console	5	"		"	Daily	*	3			
-6	Initiate Computer Interface		5	"		"	Daily	*	3			
-7	Start Data Recording		5	"		"	Daily	*	3			
-8	Calibration during experiment		5	"		"	Daily	*	3			

COSMIC RAY AND HIGH ENERGY PHYSICS LAB EQUIPMENT

- Super Conducting Magnet
- Total Absorption Shower Counter (TASC)
- Total Absorpt Nuclear Counter (TANC)
- Ionization Spectograph
- Cerenkov Counters
- Spark Chamber
- Scintillation Counter
- Proportional Counters
- Streamer Chamber
- LH_2 Target
- Transition Radiation Detector

ALL EXPERIMENTS USE EQUIPMENT FROM THE COSMIC RAY AND HIGH ENERGY PHYSICS LABORATORY EQUIPMENT AND COMPUTER PROGRAM WILL BE EXPERIMENT PECULIARY BUT SUPPORTING TASKS WILL BE THE SAME ACTIVITY CATEGORY.

*180 MINUTES/DAY

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

LEGEND OF CODES USED IN CREW ACTIVITY MATRIX

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.